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GEOPHYSICS.—*The thermal history of the earth.*[1] ARTHUR HOLMES, The University, Durham, England.

Speculation as to the thermal behavior and cooling history of the earth has been vigorously stimulated in recent years by the discovery that the radioactive elements constitute an important source of internal heat. Despite the vast store of data accumulated since Hopkins grappled with the problem nearly a hundred years ago, the constitution of the earth and the physical properties of its materials are still inadequately known, and in consequence every worker in this field finds an uncharted margin in which the undetermined conditions governing the earth's thermal history offer a considerable range of personal choice. It is for this reason that the field is occupied by several types of competing hypotheses.

RIVAL HYPOTHESES

The time-honoured "contraction hypothesis," made familiar by Kelvin, has been ably rejuvenated by Jeffreys (23). Joly, on the other hand, departing widely from traditional lines of treatment, has introduced a "hypothesis of thermal cycles" which has aroused world-wide interest and discussion (26). Convective circulation within the earth was envisaged by Hopkins in 1839 and later by Fisher (10), and a "hypothesis of sub-crustal convection currents" (maintained by the earth's radiothermal energy) is now being actively explored by Bull (6) and myself (16).

To the onlooker this overcrowded field of speculation may seem to be in a distressingly chaotic state. The occasion of this address provides me with a welcome opportunity to attempt to tidy it up. I

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propose to offer a critical survey of the whole field by systematically reviewing the physical assumptions involved in each type of hypothesis and by confronting the geological consequences of each with what is known of the realities of earth history.

RADIOTHERMAL ENERGY OF THE ROCKS

The downward increase of temperature which is everywhere encountered in the earth's crust indicates beyond doubt that the earth is losing heat. In itself, however, this fact of observation does not necessarily imply that the earth is cooling. If the interior were being heated up, heat would still be lost by conduction through the crust and radiation into space. In the well known treatment of the problem by Kelvin a steadily cooling earth was not unnaturally assumed. Kelvin regarded the earth as a spendthrift living on her inherited capital of cosmic heat. He considered (always provided that no internal supply of heat was available to counterbalance the external loss) that the present rate of cooling was represented by the average downward temperature gradient. The process of solidification from a molten state was interpreted in accordance with the belief that crystallization would begin at the surface, as happens in the lava-filled crater-sink of Halemaumau. By the formation of a succession of thin solid shells, each of which in turn broke up and sank, the earth would become a honeycombed solid enclosing cells of magma which remained available for the vulcanism of future geological ages.

To geologists the chief symptom that suggested a flaw in Kelvin's premises was his calculation that the consolidation of the crust occurred at some time between 20 and 40 million years ago. So short an allowance for geological time was widely regarded as hopelessly inadequate. The radioactive elements and their output of heat were at that time still unrecognized. But with the discovery of radioactivity and Strutt's demonstration (32) that traces of radium could be detected in all rocks, it became certain that the earth could no longer be regarded as simply a cooling body free from internal sources of heat. The long controversy came to an end with the realization that the earth must have cooled down—if at all—much more slowly than Kelvin had thought possible, and that in consequence the earth's age must be immensely greater than 40 million years.

Although the amount of radium (representing the uranium family) in rocks is very minute, the thermal effects are startling in their implications. It can easily be shown that all the internal heat lost from the earth's surface could be supplied by 1 ounce of radium in every

1000 million tons of the material of the earth. Actually the proportion in the rocks of the accessible crust averages about 1 ounce in 20 million tons. That is to say, if radium were distributed throughout the earth in the proportions characteristic of rocks the income of heat would be fifty times as great as the expenditure. Moreover, when the thermal effects of thorium and potassium are taken into account the income is found to be doubled. As we cannot believe that the earth is being heated up at this embarrassing rate, we must conclude with Strutt (Lord Rayleigh) that the radioactive elements are practically confined to a radioactive layer which corresponds with a crust a few tens of kilometers in thickness.

The suggestion that much of the energy liberated by the radioactive elements in rocks might not appear as heat has been shown by Lawson (28) and others to be entirely without foundation. Thus, if the radioactive elements are present in the substratum and core, either they must be excessively rare or their radioactivity must be in some way inhibited. The second of these alternatives is quite untenable in the light of direct experiments and modern atomic theory, but even if it were not, the reality of the radioactive layer would still remain.

Since the pioneer work of Strutt on the distribution of uranium and thorium in rocks, many other determinations have been made, notably by Joly and his co-workers, and in America by Piggot. In Figs.

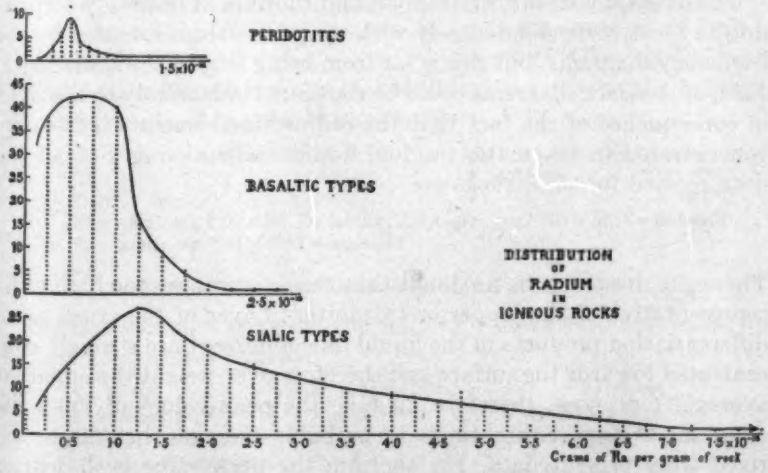

Fig. 1.—Frequency diagrams to illustrate the distribution of radium (representing the uranium family) in the three chief groups of igneous rocks.

1 and 2 I have summarized all the reliable data at present available, in the form of frequency diagrams for each of the chief groups of crustal rocks. It will be seen that, despite a considerable amount of overlapping, the rocks of sialic composition as a whole are richer in uranium[2] and thorium than those of basaltic composition, and that these in turn are richer than the rocks of peridotitic composition. It is well known that the same order is followed by potassium. Although potassium is but feebly radioactive, its aggregate heat output is important in virtue of its relative abundance in rocks.

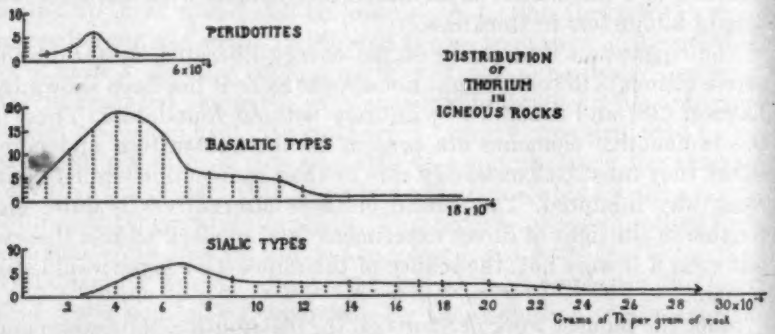

Fig. 2.—Frequency diagrams to illustrate the distribution of thorium in the three chief groups of igneous rocks.

The average contents of uranium and thorium in basaltic and peridotitic rocks correspond closely with the peak-values revealed by the frequency diagrams, but this is far from being true of the sialic rocks. Each of the sialic diagrams could be continued indefinitely to the right in consequence of the fact that the radioactive elements tend to be concentrated in magmatic residual liquids. The averages of all the data plotted for sialic rocks are:

$$\text{Radium} = 2.36 \times 10^{-12} \text{ gm./gm. i.e. Uranium} = 7.08 \times 10^{-6} \text{ gm./gm.}$$
$$\text{Thorium} = 14.8 \times 10^{-6} \text{ gm./gm.}$$

There can, however, be no doubt that these figures are too high to be representative of the Upper or "Granitic" Layer of the crust, since differentiation products in the liquid line of descent are strongly concentrated towards the surface and therefore over-weight the apparent average. I propose, therefore, to take the peak-values of the sialic diagrams as representing the most probable averages that can be derived from present data. For thorium the peak-value is ill-defined

[2] The radium contents are plotted in Fig. 1. Uranium = 3×10^6 Radium.

owing to the paucity of determinations. Nevertheless, it is thought advisable to adopt the figures given below—tentative though they be—in preference to the much higher averages that have hitherto been used for the sialic rocks of the upper layer. The averages selected are as follows:

Groups of Rocks	Uranium per 10^6 gm.	Thorium per 10^6 gm.	Potassium per 10^6 gm.
Sialic	3.75	7.0	2.7
Basaltic	2.1	5.0	0.8
Peridotitic	1.5	3.1	0.3

The order corresponds with the general downward distribution of rock-groups in the continental crust and itself constitutes evidence of a marked upward concentration of the radioactive elements. The averages for sedimentary rocks are near those here given for sialic crystalline rocks and no serious error will be involved by grouping the sediments with the latter.

It should be noticed that, however the data are treated, the inference is confirmed that acid rocks are, on an average, richer in the radioactive elements than basic rocks. The doubt as to this, recently expressed by Bailey Willis (36), is raised only by a comparison of overlapping results and is found to be baseless when the whole of the data is examined.

The rates of liberation of energy from the radioactive elements expressed as annual outputs of heat are:

Uranium family.....$7{,}900\times10^{-4}$ cals./gm. U.
Thorium family.....$2{,}300\times10^{-4}$ cals./gm. Th.
Potassium.....*ca.* 0.2×10^{-4} cals./gm. K.

Combining the data of the above tables we arrive at the following annual outputs of heat in average rocks:

Groups of Rocks	Total Annual Output in Calories per 10^6 gm.	per 10^6 cc.
Sialic	5.0	13.7
Basaltic	3.0	9.0
Peridotitic	2.0	6.8

DISTRIBUTION OF RADIOACTIVITY IN THE EARTH

Seismic evidence suggests the following downward succession for certain continental regions:

Layer	Velocity of P-waves in km./sec.	Thickness
1. Sedimentary	$P_s = 2.2$–5.0	Widely variable.
2. Upper or "Granitic"	$P_g = 5.4$–5.6	About 10–15 km.
3. Upper Intermediate	$P = 6.0$–6.5	About 15–20 km.
4. Lower Intermediate	$P_Q = 6.8$–7.1	
5. Lower	$P = 7.8+$	Extending to great depths.

Layer 2 is made up of the acid or sialic rocks of the earlier tables. The composition of Layer 3 is doubtful, but Gutenberg has shown that in North Germany this Layer approaches the surface and takes the place of the "Granitic" Layer; hence it becomes possible that Layer 3 may there be a deeply eroded Pre-Cambrian basement made up of rocks of sialic and basaltic composition such as gneisses and amphibolites. Probably in depth the Upper Intermediate Layer is more dominantly composed of amphibolite or equivalent basaltic material. It is almost certain that Layer 4 is composed of basaltic material—perhaps in the granulite facies—and that it represents the lower part of the world-wide "basaltic layer" which is widely regarded by petrologists as the source of plateau and oceanic basalts and related intrusions. At a depth of 30–40 km. the Lower Layer appears. Its composition is commonly regarded as ultrabasic, though Daly includes at least the upper part of it in his "basaltic" layer—crystalline above and glassy below. My own view is that the Lower Layer is likely to be mainly peridotite, passing down into an ultrabasic and still glassy substratum. Gutenberg and Richter (11) have found seismic evidence consistent with the belief that there is a transition from the crystalline to the glassy state at some depth between 40 and 80 km.

On the basis of this interpretation we should not go far wrong in supposing that the continental crust in certain representative places includes approximately 20 km. of sialic rocks (including sedimentary rocks where present), a similar thickness of basaltic materials, and an unknown balance of peridotitic rocks. The average annual loss of internal heat from the non-volcanic parts of the continents is about 60 calories per sq. cm. Of this amount three quarters is made good by 40 km. of sialic and basaltic materials, leaving less than a quarter to be supplied from the 6,330 km. of the underlying column. If we assume that the whole of this quarter is supplied by radioactivity and that the latter dies out at a depth of 100 km. then the temperature at this depth would be about 1540°C. An exponential distribution of radioactivity that fits the temperature gradient and approximates to the known distribution in the sialic and basaltic layers implies that radioactivity decreases by half every 18 to 20 km. down to the earth's center. The temperature at 100 km. would then be 1500° to 1530°C. At such a depth and temperature peridotite would probably be below its melting point.

There is, however, a serious objection to internal distributions of radioactivity of the two types just assumed. In the first the material of the earth below 100 km. is supposed to be entirely devoid of radio-

activity, while in the second the radioactivity falls off to extremely minute amounts which are equally improbable.

We are completely at a loss to explain how so marked a deficiency in depth could ever have been brought about. If, to begin with, the earth's radioactivity had been uniformly distributed throughout its mass, then the temperature would exceed the melting point at all depths exceeding some 40 or 50 km. Convection would then continue to operate in the glassy substratum until the radioactive elements were so strongly concentrated towards the surface that the substratum had become practically freed from them. Is there any reason for supposing that this condition has yet been achieved? The assumption that so clean a separation can have occurred finds no support in the evidence of geochemistry. Alternatively, it is conceivable that the core and substratum may have been formed from material that was originally free from the radioactive elements, or nearly so, and that the peridotitic, basaltic, and sialic materials of the crust were added later from a source more richly endowed in the radioactive elements. The view that the substratum contains "normal" amounts of the "radioactive" elements but that for some unknown reason they each in turn cease to be radioactive at some critical depth is quite untenable in the light of existing knowledge. Nevertheless, we have at present no means of reaching an unequivocal conclusion. All we can do is to follow up the consequences of two possibilities, one of which must be true:

(A) The substratum may be so nearly free from radioactive elements that the earth can have systematically cooled down in one or other of the ways on which the contraction hypothesis is based.

(B) The radioactivity of the material of the substratum—though of a feeble order compared with that of the crust—may be in excess of the extreme limitation imposed by the requirements of the contraction hypothesis. If so, the temperatures of the interior may still be maintained above the freezing-point.

In alternative B, part of the supply of internal heat must escape sooner or later by processes other than conduction through the crust. Igneous activity is the most spectacular example of such processes. It is important that this function of igneous activity should not be overlooked. In my own early work (14) I began with possibility A and it has been claimed for my treatment that it was satisfactory because it coordinated successfully all the thermal data (Adams, 1 and Jeffreys, 20). I later rejected A, however, precisely because it did not seem to be consistent with the occurrence of certain types of igneous

activity, such as the eruptions of plateau basalts (15). These, after all, represent an important part of the thermal data. It is true that any local increase in the thickness of the radioactive layers of the crust (e.g. in belts of geosynclinal sedimentation and subsequent mountain building) must lead to a considerable rise of temperature in depth, thus favoring the production of magma by refusion and the initiation of vulcanism. But flood-basalts and plateau-basalts have commonly ascended in regions like the Deccan where the crust had already been deeply denuded; that is to say, in regions where the radioactive sialic layer had been thinned. The source of the excess heat necessary to generate magmas in such a geological setting can be looked for only in the substratum, which must therefore have within itself an excess of heat, at least at certain times and places.

The same conclusion may be reached even for the belts of crustal thickening. Radioactive heating in the deep sialic roots of mountain ranges would certainly be competent to bring about the production of granitic magma on a vast scale—but only after the lapse of a hundred million years or more. As granite appears during and immediately after mountain building we have a direct proof that the necessary heat must have come from the substratum. This conclusion is consistent with two other sets of facts: first that contemporaneous vulcanism has commonly occurred during the infilling of the geosynclines from which the mountains afterwards arose; and second that in igneous complexes the usual order of plutonic intrusion is from peridotite through gabbro or diorite, or both, to granodiorite and granite.

It thus appears at the outset that possibility B offers a better chance of accounting for igneous activity than the alternative A. As the latter is based on temperature gradients in regions which have ceased to be volcanic, it cannot be expected to account for volcanic activity. On the other hand, it may be objected that B goes too far since it would seem to require the possibility of vulcanism everywhere and at all times. A reasonable answer is that at any given place the thicknesses of the crustal layers, and the thermal state of the substratum immediately below, may vary from time to time. Variations of both types are necessary consequences of the convection hypothesis and of Joly's hypothesis of thermal cycles.

PHYSICAL BASIS OF THE RIVAL HYPOTHESES

It has already been tacitly assumed that the earth began its thermal history as a fluid globe. It is probable that the first effects of the

cooling of a gaseous earth (by internal convection and radiation into space) would be the condensation of a succession of liquid phases. Core and substratum would appear first. These would separate in virtue of the immiscibility of their respective liquids. It is to be expected that the magma of the basaltic layers would follow that of peridotite without a break, and that granitic magma would condense next. The lateral discontinuity of the granite layer which is responsible for the existence of continents still offers an unsolved problem. Long after the granite had crystallized, the waters of the hydrosphere would begin to be precipitated. This conception of the early cooling history embodies a possible clue to the reason for the concentration of radioactivity in the crustal layers. It cannot be tested at present because we know nothing of the way in which traces of volatile compounds of uranium and thorium would distribute themselves between liquid and gaseous silicate phases.

The substratum, if produced in this way, would be liquid from the start. It would cool by convection, transmitting its heat to the overlying layers, until somewhere within it the freezing temperature, under the pressure of that depth, was reached. We must next consider whether the freezing temperature would first be reached at the top, at some intermediate depth, or at the bottom.

Convection can continue only so long as a certain downward increase of temperature is exceeded; for convenience this downward increase may be referred to as the convection gradient. The variation of freezing point with pressure corresponds to another gradient which may be referred to as the freezing- (or melting-) point gradient. As shown in Fig. 3., if the freezing-point gradient is steeper than the convection gradient, crystallization must begin at the bottom. If, on the contrary, the convection gradient be the steeper then crystallization begins at the top (Fig. 4). The importance of this distinction was first recognized by Hopkins, but it was left for Dr. L. H. Adams (1) to show that under the pressures corresponding to crustal conditions the freezing-point gradient is the steeper. Such data as we have for silicates suggest that the convection gradient is about 0.3°C. per km. whereas the freezing-point gradient is about 3°C. per km. If this relation continued throughout the thickness of the substratum, then crystallization would first begin at the bottom and a steadily increasing thickness of ultrabasic rock would accumulate until the whole had consolidated. This is certainly one possibility that must be reckoned with.

But here, too, there is an alternative to be considered. Tammann (33) has conjectured from the behaviour of certain hydrous salts that with increase of pressure the melting point of silicate materials may rise to a maximum temperature and then begin to fall again (Fig. 5). If this view were valid, then the curve representing the convection gradient would first touch the freezing-point curve near the peak of

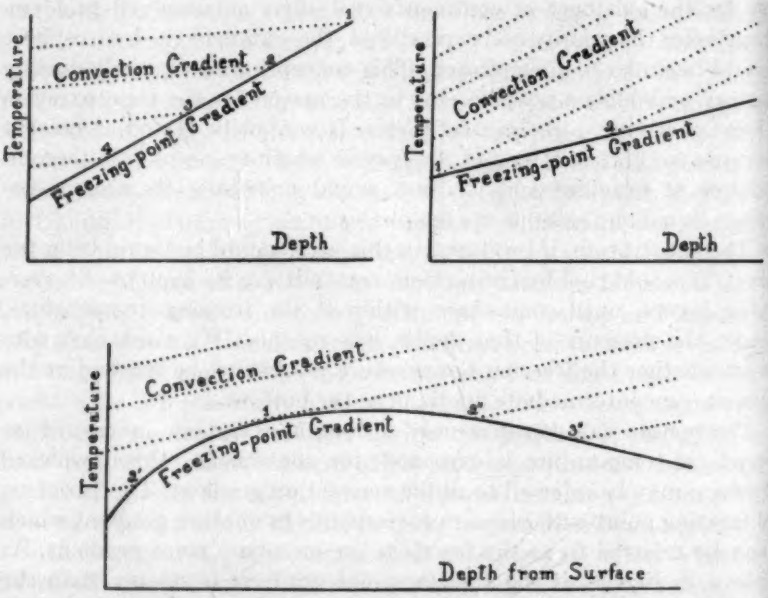

Fig. 3.—Illustrating the course of crystallization in the Substratum from below upwards if the freezing-point gradient be steeper than the convection gradient.

Fig. 4.—Illustrating the course of crystallization in the Substratum from above downwards if the convection gradient be steeper than the freezing-point gradient.

Fig. 5.—Illustrating the beginning of crystallization at some intermediate depth in the Substratum where the convection gradient is tangential to the freezing-point gradient.

the latter, and crystallization would begin at the intermediate depth where the two curves first became tangential. Bridgman (2) has shown, however, that "the evidence * * * seems to be unequivocally against the possibility of a maximum temperature." With hydrous salts the existence of a maximum is a consequence of the effect of pressure on solubility. While this additional effect may, of course, operate in the substratum, which is not likely to be a pure substance, it is improbable that it can be the controlling factor. Bridgman favors the

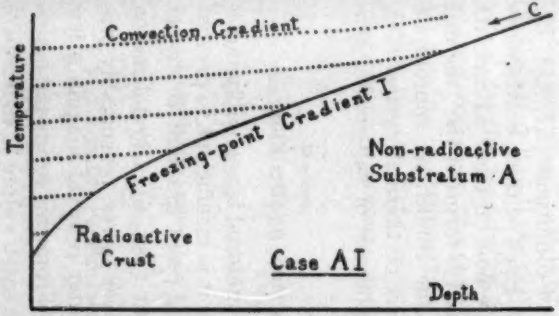

Fig. 6.—Case AI: Thermal conditions appropriate to the "Thermal contraction hypothesis."

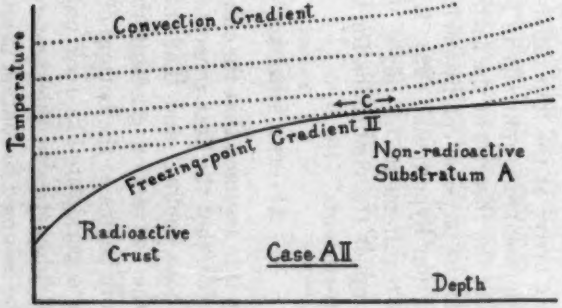

Fig. 7.—Case AII: Thermal conditions appropriate to a modified form of the "Thermal contraction hypothesis."

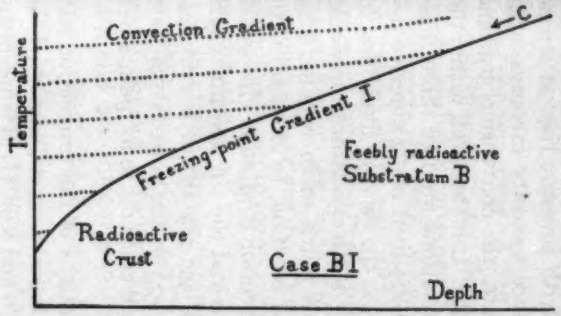

Fig. 8.—Case BI: Thermal conditions appropriate to the "Hypothesis of thermal cycles."

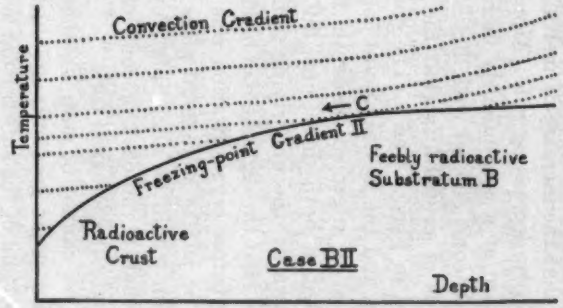

Fig. 9.—Case BII: Thermal conditions appropriate to the "Hypothesis of subcrustal convection currents."

view that the increase of melting point with pressure rises at a continuously decreasing rate. Moreover, since viscosity increases with pressure at a continuously increasing rate, the convection gradient must become steeper with increasing depth. It is thus well within the bounds of probability that the actual relations are like those illustrated in Figs. 7 and 9. The convection gradient being concave upwards and the melting-point curve convex, the two are likely first to meet at an intermediate depth. From this depth crystallization would proceed in both directions, but upwards much more rapidly than downwards; the underlying liquid would continue to circulate until loss of heat through the roof brought convection to an end. This would occur before crystallization was complete and the substratum would then be left as a stagnant glass in which the rate of further crystallization would be negligibly slow. If however, the substratum were only slightly radioactive, convection would continue to be maintained throughout geological time.

As we cannot be sure whether the relations of the convection and freezing-point gradients are such as to initiate crystallization, I, at the bottom of the substratum as in Figs. 6 and 8 or, II, at some intermediate depth as in Figs. 7 and 9, we must follow up the consequences of each alternative. Combining I and II with the two possibilities A and B depending on the distribution of radioactivity in the substratum, we arrive at the four different sets of conditions (AI, AII; BI, BII) represented graphically in Figs. 6–9. Each of these corresponds to one of the theories of the earth that are now on trial. AI and AII provide the physical conditions for alternative forms of the "thermal contraction hypothesis" (23). BI gives the conditions appropriate to the requirements of Joly's "hypothesis of thermal cycles" (26). BII supplies the conditions for the "hypothesis of sub-crustal convection-currents" (16).

AI—THE THERMAL CONTRACTION HYPOTHESIS

Here it is assumed that the sub-crustal material is negligibly radioactive (i.e. that the heat generated within it is insufficient to prevent continuous cooling) and that the freezing-point gradient is steeper than the convection gradient throughout (Fig. 6). Crystallization therefore begins at the bottom of the Lower Layer, presumably producing a peridotite-like rock until an outer residual magma a few tens of kilometres in thickness remains. From this residuum, which must be assumed to contain nearly all the earth's store of radioactive

elements, layers of basaltic and granitic composition crystallize in turn.

The consequences of the contraction hypothesis have been repeatedly discussed, and despite the damaging criticism to which the hypothesis has been exposed, many geologists still retain their faith in its tenets. In 1930, for example, Hobbs (13) expressed his belief that "this view of a shrinking earth is more firmly established today than ever before." On the other hand, Wegener regarded the hypothesis as "completely bankrupt." Both authors omitted to give sound reasons for their contradictory opinions, but at least two sets of considerations seem to me to support Wegener's characteristically sweeping judgment.

As indicated already on p. 176 the thermal limitations of the hypothesis preclude its successful application to the outstanding phenomena of igneous activity. The widespread occurrence of plateau basalts and the appearance of plutonic intrusions during orogenesis seem to be quite inconsistent with the existence of a crystalline interior (19).

Jeffreys has claimed that the compression due to contraction is of the right order to account for mountain-building, and the validity of his claim has been as persistently denied. On both sides, however, the margin of error is so great that a really convincing comparison between theory and fact is at present out of the question (17 and 24). On the other hand, the distribution of mountain-building in time, as tested by the lead-ratios of radioactive minerals, shows that the intervals between the peaks of successive orogenic revolutions have not become systematically longer, as they should have done, according to the hypothesis. Indeed, since Pre-Cambrian time the intervals have become shorter, as the following data clearly show (18).

Orogenesis	Lead-ratios	Intervals
Alpine-Laramide	0.008	
		0.022
Hercynian-Appalachian	0.030	
		0.025
Caledonian-Taconic	ca. 0.055	
		0.030
Upper Pre-Cambrian	0.085	
		0.045[a]
End of Middle Pre-Cambrian	0.130	

[a] It is possible that this interval represents two intervals of 0.025 and 0.020 divided by the Killarnean orogenesis with a lead-ratio of 0.110.

This apparent speeding-up of the earth's orogenic activities is demonstrated in detail by Figs. 10 and 11. In Fig. 10 a first approximation to a geological time-scale is provided by plotting lead-ratios against maximum thicknesses of sediments from the Cambrian onwards. The steepening of the curve as the present is approached accords with the findings of Barrell and Schuchert to the effect that rates of denudation and sedimentation have steadily increased since Pre-Cambrian time. In Fig. 11 the orogenic episodes recognised by Stille are plotted against the time-scale. The results show at a glance that there has been a remarkable acceleration of activity.

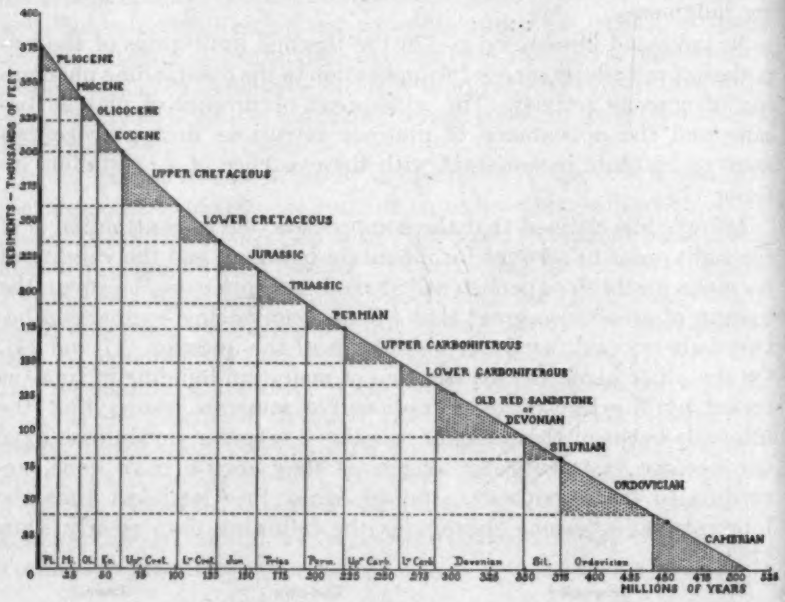

Fig. 10.—An approximate geological time-scale based on lead-ratios (plotted as abscissae) and maximum thicknesses of sediments (plotted as ordinates).

The contraction theory implies an ageing earth that should now have reached senility. The fact is that during the Tertiary period the earth was more vigorous in her behaviour than ever before during at least the last thousand million years. Many other objections to the hypothesis could be urged, but those here given seem to be ample to justify its rejection.

AII—MODIFIED FORM OF THE THERMAL CONTRACTION HYPOTHESIS

In this case (Fig. 7) the assumed distribution of radioactivity is that of AI, but the two gradients are regarded as becoming tangential at some intermediate depth. Crystallization begins at this depth and proceeds upwards as in AI. Crystallization—or possibly consolidation into the durovitreous state—also proceeds downwards into the underlying zone of convection so long as the heat brought up can be carried away by conduction through the crust. The underlying convective zone slowly thins and dies out by downward thickening of the crust as loss of heat reduces the gradient below the critical value. The bulk of the substratum is then left as a stagnant glass in which downward crystallization very slowly proceeds. The period required for complete crystallization would be very long compared with geological time. This form of the contraction hypothesis implies that the substratum was practically devoid of radioactivity from the start, since the cooling process in itself provides no mechanism for concentrating any originally dispersed radioactivity towards the surface.

Jeffreys finds that on this hypothesis crystallization may now have proceeded to a depth of a few hundred kilometres. As compared with AI a little more contraction may be available because of the volume change attending crystallization or the passage from the liquevitreous to the durovitreous state. On the other hand the gradient due to the

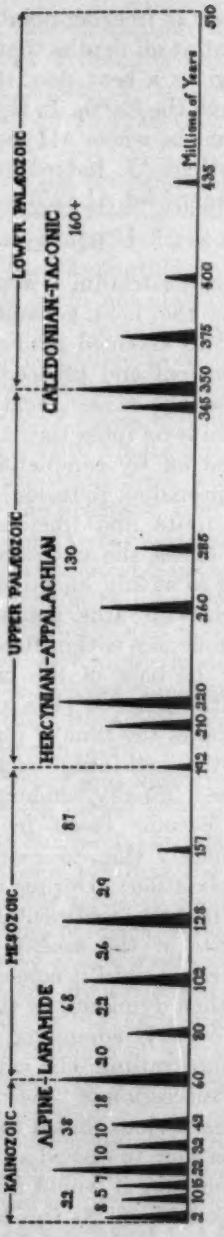

Fig. 11.—Orogenic episodes (after Stille) of Post-Cambrian time plotted on the time-scale of Fig. 10. An assessment of the relative intensities of the respective orogenies is roughly indicated by the heights of the black triangles.

increase of freezing-point with depth—which gives rise to an outflow of heat at all depths that have crystallized—is less steep than in AI, and gives a heat flow through only a shallow depth instead of all through the Earth. In this respect, therefore, there is less contraction, and on the whole AII seems to be even less capable of matching the facts than AI. Indeed, in his latest work Jeffreys clearly shows his preference for AI (25).

BI—HYPOTHESIS OF THERMAL CYCLES

The substratum is assumed to be slightly radioactive, sufficiently so for the heat generated to prevent permanent crystallization. The two assumed gradients being as in AI, crystallization begins at the bottom and proceeds towards the surface (Fig. 8). Once convection has ceased, heat is generated at all depths below a certain critical level (near the base of the basaltic layer) faster than it can be carried off by conduction. This excess of heat supplies latent heat and promotes re-fusion. Sooner or later the growing threads of fluid unite and liberate crystal individuals or aggregates which sink, unless the viscosity is sufficiently high to prevent them from doing so at any effective rate. A layer of magma thus accumulates and rises upwards, increasing in thickness as it ascends. Convection recommences within this layer, and accelerates the upward migration until the base of the basaltic layer is reached. Re-fusion of the basaltic material then proceeds. At this stage the temperature at the top of the zone of fusion is below the freezing-point of peridotite and the peridotite magma gradually solidifies as the basaltic layer is fused. Finally, under the continents, much of the granitic layer may become fused in turn before the overlying crust becomes sufficiently thin to carry off the excess of heat and bring about consolidation. During the later stages, igneous activity is inevitable in both continental and oceanic regions. Essentially the cycle consists of the ascent of a wave of fusion from great depths, thickening until it comes under the cooling influence of the surface, and then dying out as the surface is closely approached. Before the first cycle is completed another will have begun in the depths of the substratum. The earth's history is thus thought to be controlled by a succession of "thermal cycles."

It is obvious that if the maximum depth ever reached by a zone of fusion were to exceed a certain thickness (of the order of a few tens of kilometres,) it would fail to die out before breaking clean through to the surface. As this has not happened on a regional scale within

known geological history there is here a clear indication that the hypothesis cannot legitimately invoke waves of fusion of more than relatively small amplitude. This limitation implies an average radioactivity in the substratum of a much lower order than that of the crust (1/100th or less).

It was assumed in the above statement that the viscosity of the substratum was not too high to prevent the effectual sinking of crystals. Actually, however, the viscosity is extremely high; Jeffreys finds a mean value exceeding 5×10^{20} c.g.s. from the 14-monthly variation of latitude. Under such conditions crystals could not sink through any appreciable distance during geological time. Thus the conditions favourable to thermal cycles would seem to be limited to within 100 km. or so from the surface. But as fusion would nevertheless steadily proceed throughout the substratum, successive cycles or groups of cycles would involve ever-increasing depths, until finally a wave of fusion would rise of such amplitude that the whole crust would be engulfed, and in part remelted. Accepting the premises, it is by no means inconceivable that such a fate may overtake the earth at some remotely future time. The danger arises from the conditions implied by the hypothesis under consideration; first, the rising convection currents maintain temperatures at the top that are well above the melting-point of the materials of the roof; and second, the heat represented by the excess of temperature over the melting point, and the latent heat of the material of the wave of fusion, have both to escape through to the surface before reconsolidation can occur.

The advantages of Joly's hypothesis are many, but unfortunately they are both dangerous and incomplete. Each period of consolidation corresponds to one of crustal contraction and mountain-building, and in this respect the hypothesis is more satisfactory than the traditional contraction hypothesis, as it provides for repeated consolidations, each time beginning afresh from conditions of fusion. Obviously, there is ample opportunity for igneous activity on the most extravagant scale. Marine transgressions and recessions are a necessary consequence of thermal cycles. Partial foundering of the lands and their invasion by epeiric seas take place during conditions of widespread fusion, followed by recovery and withdrawal of the seas during the succeeding phase of contraction and orogenesis.

Jeffreys has vigorously attacked the hypothesis on physical grounds (21 and 22). Joly requires a westerly tidal drift of the crust to drag the ocean floors over the magmatic layer and so permit the excess sub-continental heat to be discharged through the chilled and atten-

uated oceanic part of the crust. Jeffreys gives good reasons for thinking that this drift could not occur at the required rate. On the other hand, J. H. J. Poole (31) has developed a form of the hypothesis in which tidal drift does not appear. McCarthy (29) has pointed out that rapid loss of heat through the oceanic floors would involve abnormal heating of the oceanic waters, and this consideration undoubtedly limits the application of the hypothesis to a very thin layer of fusion. A serious objection to the hypothesis in its ideal symmetrical form is its implication that world-wide crustal tension (during fusion and expansion) has alternated in time with world-wide compression (during consolidation and contraction). The testimony of geology is that compression seems always to have been more or less active somewhere or other in the world, periodicity being a matter of climaxes in particular regions heralded by crescendos and followed by diminuendos. Moreover, tensional phenomena have often been contemporaneous with compressional phenomena elsewhere. It might be possible to modify the hypothesis so that it would become consistent with these phenomena, but to do so would necessitate the discovery of a non-uniform distribution of radioactivity in the crust on a regional scale and to an extent that the evidence so far collected fails to foreshadow. Like the thermal contraction hypothesis, this one equally fails to account for the development of geosynclines, the subsiding areas of long-continued sedimentation that formed the gathering ground of the formations out of which long belts of mountain ranges were destined to be built. It must also be pointed out that Joly's hypothesis is at variance with the rate of the apparent speeding-up of geological activities to which reference has already been made. Certainly successive cycles would be of increasing intensity if each wave arose from a greater depth than the previous one, but if so the time intervals between them would become systematically longer.

Although it seems highly improbable that the hypothesis of thermal cycles can by itself express the earth's thermal history, it would be rash to deny its applicability to certain of the problems of crustal thermodynamics. The formation, ascent, and consolidation of magmas and consequent isostatic changes of level seem to fall within the scope of its mechanism, but on a scale less grandiose than that visualized by its author.

BII—HYPOTHESIS OF SUB-CRUSTAL CONVECTION CURRENTS

Here it is assumed that the gradient in the convecting layer becomes tangential to the freezing point gradient at some intermediate

depth (Fig. 9). Tangential conditions are likely to be closely approached through a zone of considerable thickness. Crystallization begins in this zone and proceeds upwards until a crust is formed over a convecting interior. Under these conditions the rising convection currents reach the overlying roof at or near the temperature of the melting point of the roof materials. Moreover, the latent heat of the substratum below the level of tangency is not liberated by crystallization and does not escape through the crust, since crystallization tends to occur only at and above the level of tangency and not at the bottom of the substratum. Only the latent heat of material fused *above* the level of tangency has to pass through the crust. From this cause there is therefore no danger of catastrophic crustal fusion on a world-wide scale after the crust has once formed. The substratum remains in a glassy state (liquevitreous of Jeffreys), characterized by rigidity, high viscosity, no permanent strength, and sufficient radioactivity to maintain a slow but ever-changing convective circulation.

It is easy to see that the zone of tangency must lie beneath the basaltic layers. It cannot be in the latter because of the marked fall of melting-point in passing upwards from peridotitic to basaltic material. On the other hand, if the zone of tangency were deep in the peridotitic layer, the crust would be too thick to carry off by conduction the heat brought up by rising convection currents. The peridotitic layer would then heat up, and its temperature gradient would steepen, until the actual zone of tangency migrated to a higher level. This implies partial fusion of the lower part of the peridotitic layer and the generation of successive waves of magma which would ascend into the crust as in the Joly cycles. The evidence of igneous activity indicates that such waves are relatively thin, whence it follows that the shell of material fused by the ascent of the zone of tangency must itself be thin. An average depth for the zone of tangency between 40 and 80 km. would seem to coordinate all the relevant data. Such a depth corresponds first with that suggested by Gutenberg and Richter (11) for the passage from the crystalline to the glassy state; and second, with the thermal necessity that conditions of fusion must normally reach a level some distance above the depth where the melting point would be attained in virtue of the radioactivity of the overlying material.

The above discussion indicates that variations in the thickness and radioactivity of the crust, together with changes in the temperature gradient of the substratum, may combine to extend very considerably the range of the shell subject to refusion. For this reason the condi-

tions which determine whether the substratum gains on the crust by upward melting or the crust gains on the substratum by downward crystallization are likely to vary from place to place and from time to time.

To prevent convection in a layer extending far down towards the core a viscosity exceeding 10^{26} would be necessary. As we have good evidence that the actual viscosity is well below this limit there is no physical improbability about internal convection. Vertical currents ascend in certain places and on reaching the top the material promotes sub-crustal fusion and spreads out laterally, flowing horizontally to the neighboring descending currents. The horizontal flow is likely to exercise a powerful viscous drag on the lower levels of the crust, throwing the latter into tension where the currents diverge and into compression where they converge (Figs. 12 and 13). If the distance between ascending and descending currents be of continental dimensions then the drag due to horizontal flow may produce continental displacements, with distension behind and mountain-building in front. Material from the substratum ascends into the distended area, where it cools, and differentiates, while heavy compressed crustal material (eclogite from the basaltic layers) is dragged down with the descending currents.

Excess heat from the substratum is thus discharged (*a*) by cooling due to thinning of the crust and consequent development of basins,

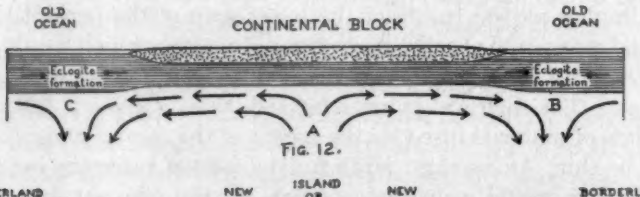

Fig. 12.

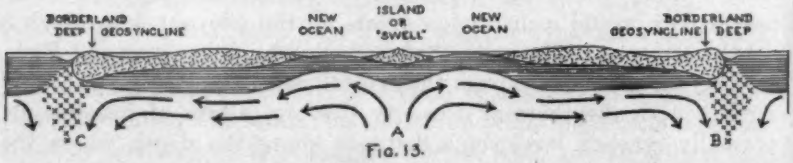

Fig. 13.

Fig. 12.—Sub-continental circulation in the Substratum with eclogite formation from the basaltic rocks of the Intermediate Layer above B and C where the sub-continental currents meet sub-oceanic currents and turn down. Upper "Granitic" Layer, dotted. Intermediate Layer (gabbro, amphibolite, basic granulite, etc.), line-shaded. Substratum, unshaded.

Fig. 13.—Distension of the continental block on each side of *A* with formation of new ocean floors from rising basaltic magma. The front parts of the advancing continental blocks are thickened into mountainous borderlands with oceanic deeps in the adjoining ocean floor due to the accumulation of eclogite at B and C.

geosynclines or ocean floors over the sites of ascending currents; (*b*) by the heating-up and remelting of crustal materials carried down in descending currents; and (*c*) by igneous activity of all kinds.

The convection hypothesis has the advantage over its rivals that it naturally and inevitably provides for simultaneous tension and compression. Good examples of this are the opening of the Uralian geosyncline at the same time as the crumpling up of the Caledonian mountains of Scandinavia, and the formation of the North Atlantic while the Rockies, Sierras, and Coast Ranges of Western North America were being formed.

According to the convection hypothesis, we should expect mountains to be formed where two series of approaching currents turn down and so compress the overlying layers of the crust (Figs. 12 and 13). Experiments by Bull (5) have shown that this kind of mechanism provides the only method yet devised for successfully imitating nappe-structures like those of the Alps. While the mountains are being built from sialic materials, the underlying basaltic material is dynamically metamorphosed into the dense eclogite facies and is sucked down by the downward-flowing currents. After the folding, some of this material will in many places remain beneath the orogenic belt, and its inevitable fusion must tend to heave up the overlying mountain range. Where it happens, however, that the fused material is squeezed out sideways, the mountain chain will break down and parts of it may even subside beneath sea-level. Other parts of a folded belt may never have risen above the sea.

Jeffreys has pointed out that many old peneplained mountain ranges are still represented by tracts of folded sediments, despite the fact that if they had been worn down to this extreme degree by denudation alone, all the sediments and much of the underlying granitic layer should have been removed (23, p. 296). He suggests that these tracts have in part been lowered by "outflow of matter from the intermediate layer, with compensating inflow in the lower layer." Such an effect would be brought about equally well by the passage of a sub-crustal current, for the latter would tend to "erode" the roots, carrying away the corroded material in the direction of movement, just as ice-sheets have ground down the protuberances of the land surface beneath them and spread out the debris in the lowlands beyond.

The distribution of the latest of the earth's mountain systems (Figs. 14 and 15) shows that they form interrupted rings surrounding the great northern land masses of N. America and Eurasia (known

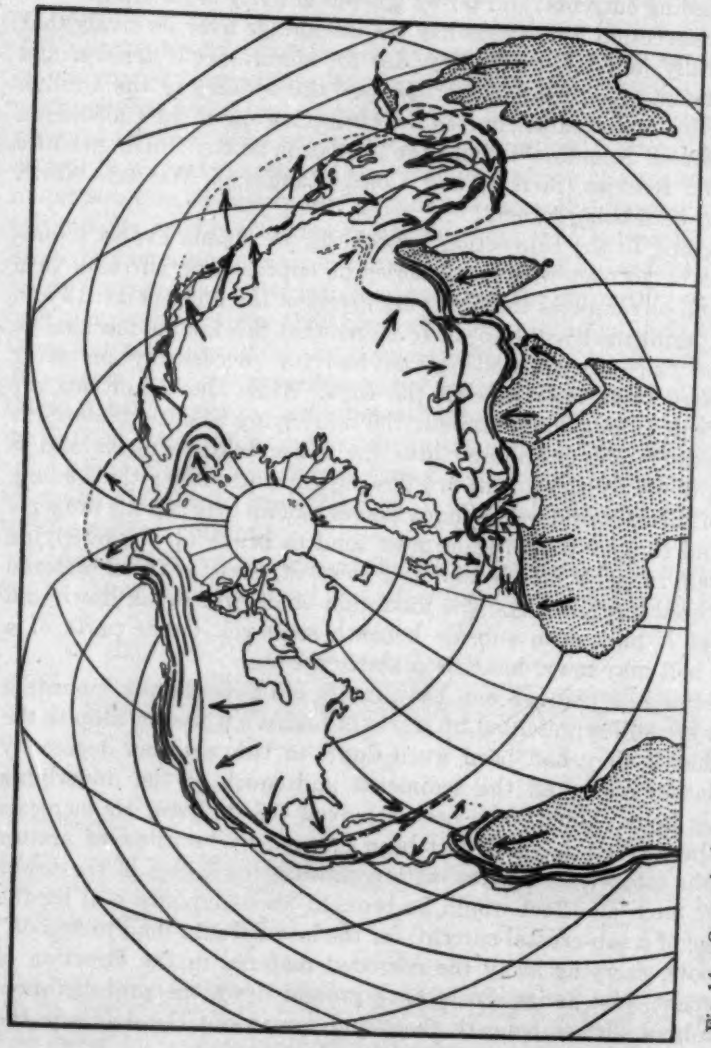

Fig. 14.—Orogenic ring peripheral to Laurasia with continental movements directed outwards towards the Pacific and the Tethys. (The adjoining blocks of Gondwanaland are dotted.) Scale: 1: 170×10⁶.

as Laurasia) and the southern lands of S. America, Africa, India, Australia, and Antarctica (known as Gondwanaland). Each great land mass seems to have been the centre of a system of currents directed outwards towards the Pacific and towards the former Mediterranean—the Tethys—that lay between Gondwanaland and Laurasia. Peripheral ranges of mountains were raised up in front of each advancing continental block—and in some places, such as the East and West Indies, the process seems still to be in operation. Earthquakes and volcanoes are specially numerous in and adjacent to these peripheral rings of crustal instability.

Fig. 15.—Orogenic "ring" peripheral to Gondwanaland (dotted) with continental movements directed towards the Pacific and the Tethys. Scale: 1: 210×10⁶.

The formation of eclogite in front of active mountain ranges is strongly suggested by the oceanic deeps of the western margins of the Pacific. Here, too, lie the epicentres of many deep earthquakes that have originated from foci hundreds of kilometres below the surface (35). If these deep-seated disturbances are not in some way a result of currents operating far down in the zone of flowage where great masses of eclogite may be fractured as their strength is overcome, it is difficult to conceive an alternative mechanism that could be responsible for them.

The action of sub-continental currents directed towards the Pacific shores may be inferred from the echelon structure of the island festoons of Asia (34), and from the great and geologically rapid uplifts of the outer zones of many growing island-arcs (Hobbs, 12). Evidence of a different sort, suggesting the action of a sub-Pacific current, is forthcoming from a comparative study of certain coral reefs in the Fiji group made by W. M. Davis. It will suffice here to quote a single sentence from the paper referred to (8): "The changes of level in the several belts all appear to be caused by the slow westward migration of a broad and low ocean-floor anticline, preceded and followed by shallow ocean-floor synclines." Substratum currents acting on the under surface of the crust may be expected to produce migrating sub-crustal wave-forms which would be mirrored above by migrating anticlines and synclines of the kind discovered by Davis.

The remarkable belt of negative anomalies of gravity recently discovered by Meinesz in the East Indian Archipelago (30) may also be a symptom of sub-crustal currents. A powerful downward drag seems necessary to account for the astonishing departure from isostatic equilibrium that has been revealed (17). Other anomalies, however, such as those which imply that the equator of the geoid may be slightly elliptical instead of circular, have been used by Jeffreys in support of the view that the substratum has sufficient strength to withstand considerable regional departures from isostatic equilibrium (23, p. 222). If the substratum has strength, its viscosity is infinite until the strength has been overcome, and convection currents would then be impossible. The objection is not final, however, for its acceptance raises in turn a fresh difficulty. If Africa, for example, stands high to an extent implying a slight bulge in the equator, then its tendency should be to sink; yet actually its tendency has been, and geologically speaking, still is, to rise. I have therefore suggested the alternative interpretation that the "bulge" may be an

expression of some dynamic process operating in the substratum at a rate slightly in advance of that of isostatic re-adjustment (16, p. 576). There is here a difference of opinion that should be amenable to mathematical treatment and decision.

Turning to evidence of a very different kind, it is worthy of notice that the maintenance and secular variations of the earth's magnetic field are regarded by Chapman (7) as possible consequences of a deep-seated internal circulation of material. Another suggestive indication of flowage in the substratum is provided by the mysterious fluctuations in the earth's rate of rotation which have been studied by de Sitter (9) and Brown (3). De Sitter points out that the sudden shortening of the day which happened in 1918 could have been produced "by a very slight adjustment of the layers of equal density in the inside of the earth, of which the effect on the dimensions of the outer surface need not exceed a fraction of a millimeter." The significance of this statement is best realised by considering that "if the whole of the Central Asian Highlands from the Himalaya to the Kwen Lun Mountains (both included) had at that time been sunk into the earth, their mean height being reduced to sea-level, the resulting shortening of the day would have been only one fourth of what is required." We have in such remarkable time-changes an indubitable indication of deep-seated widespread movements within the earth—movements which must, moreover, arise from causes originating inside the earth, quite independently of any external cause due to sun, moon, or stars.

So far, little has been said about continental drift, and space does not allow of any critical discussion of the evidence for or against it. It may be said, however, that on the thermal contraction hypothesis continental drift is manifestly impossible, whereas on the convection hypothesis a certain amount of drift is inevitable mechanically; it serves, moreover, to provide a means of escape for the heat carried up to the crust by the more powerful ascending currents. The convection process seems also to be intimately related to the acceleration of geological activities since Pre-Cambrian times, and to the cognate fact that continental drift does not appear to have operated on a considerable scale until after the Hercynian orogenesis. If eclogite is carried down by descending currents into the substratum, then some of the basaltic material must be dissolved in the substratum which, in consequence, becomes locally enriched in the radioactive elements. The tendency to circulate in convection currents should, therefore, have become more marked with the advance of geological time, and this would necessarily have provided more earth movement, more

igneous activity, and in general more intense manifestations of energy in every direction. The explanation suggested implies that the radioactive layer was not concentrated from the interior, as generally assumed, but that conversely, the interior has been steadily gaining radioactivity at the expense of the lower levels of the crust. If so, the earth has an exciting geological history in store.

Although the hypothesis invoking sub-crustal convection currents cannot be regarded as established, it is encouraging to find that it is consistent with a wide range of geological and geophysical data. Moreover, it is by no means independent of the best features of the other hypotheses. It requires the local operation of thermal cycles within the crust, and it necessarily involves contraction in regions where crustal cooling takes place. It is sufficiently complex to match the astonishing complexities of geological history, and sufficiently startling to stimulate research in many new directions. And therein lies its chief merit, whether it fails or succeeds. Jeffreys (24) can find nothing inherently impossible in the hypothesis, but he thinks that "its validity would be a remarkable accident." I agree; but then I think the earth is no less a remarkable accident. It is impossible to be a geologist without realising that—in the dim light of the knowledge we have so far gained—the earth we live on is a strange and most improbable planet.

Of the figures which illustrate this paper Figs. 1–13 have been drawn for me by my friend Miss Doris L. Reynolds and in conclusion I wish to record my grateful thanks for her generous cooperation. The two maps, Figs. 14 and 15, are reproduced from an earlier paper (16) by permission of the Council of the Geological Society of Glasgow.

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CRYSTALLOGRAPHY.—*The crystal structure of tenorite (cupric oxide).*[1]

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The monoclinic symmetry of the thin tenorite crystals from Vesuvius has been established by Tunell and Posnjak (details not yet published); the proof consisted in the demonstration that the extinction position remained stationary when the crystal was rotated

[1] Received February 28, 1933.

around the b axis. The b axis also bisects the angle formed by the traces of the two perfect cleavage planes.

The monoclinic symmetry of an artificial single crystal of cupric oxide prepared for this crystallographic study was established independently by x-ray analysis. The identity of artificial cupric oxide and the thin tenorite crystals from Vesuvius was established by a number of powder photographs. The unit cell dimensions a_0, b_0, c_0, and β of artificial cupric oxide were calculated from measurements made on rotation and Weissenberg pictures. Powder and rotation photographs were taken with Mo-radiation and also with Cu-radiation. Weissenberg pictures of the equator and first and second layer-lines were taken with Cu-radiation and were analyzed by the construction of Schneider.[2] With the Weissenberg x-ray goniometer the direction of the normal to each atomic plane of a crystal of any system and also the spacing along each normal can be uniquely and rigorously determined even if the crystal has no external faces; the unit cell dimensions a_0, b_0, c_0, and β of a monoclinic crystal can thus be calculated. The dimensions of the unit cell calculated from the measurements with Mo-radiation are $a_0 = 4.66$Å, $b_0 = 3.40$Å, $c_0 = 5.09$Å, all $\pm .02$Å, $\beta = 99°30' \pm 30'$; slightly more accurate measurements have been made with Cu-radiation and the unit cell dimensions calculated from them will be given in the final report. The dimensions given yield an axial ratio that agrees well with that calculated by Scacchi[3] from measurements made by Jenzsch[4] with a reflection goniometer on crystals formed in a smelter-hearth near a flue at Freiberg in roasting copper matte with sodium chloride, and also with the axial ratio of Story-Maskelyne.[5] Our x-ray measurements are also in good agreement with measurements made by us on a Goldschmidt reflection goniometer, as well as with the older measurements, as is shown in the following table.

The atomic structure was deduced from the relative intensities of the diffraction lines and spots, and the parameter was determined. Thus a complete solution was obtained by means of the Weissenberg x-ray goniometer. By comparing a list of the planes affording diffraction spots with the "Röntgenographische Auslöschungstabellen" of K. Herrmann[6] we found that a perfect correspondence exists with the

[2] Zeit. f. Krist., 69: 41. 1928.
[3] Contribuzioni mineralogiche per servire alla storia dell' incendio vesuviano del mese di Aprile 1872, p. 12, Atti d. R. Accad. d. Sc. fis. e. mat. Napoli. 6: 1875.
[4] Poggendorff's Ann. d. Phys. u. Chem., 107: 647. 1859.
[5] Verh. Petersb. Min. Ges., 1: 147. 1866.
[6] Zeit. f. Krist., 68: 288. 1928.

TABLE 1. PRISM ANGLE OF TENORITE ($f \wedge f$).

Jenzsch (Reflection Goniometer)	72°57½′
Story-Maskelyne (Reflection Goniometer)	73°18′
Tunell, Posnjak, Ksanda (Reflection Goniometer)	72°59′
Tunell, Posnjak, Ksanda (X-ray Goniometer)	72°51′ ± 30′

theoretical extinctions of the space groups, $C2/c$ and Cc (C_{2h}^6 and C_s^4), the extinctions of these two space groups being identical. A decision between these two space groups is of course not possible by a consideration of extinctions alone. However, the intensities of the diffraction spots point strongly to an arrangement of the atoms of cupric oxide in special positions of $C2/c$ (C_{2h}^6), a conclusion strengthened by the fact that the crystal habit observed in the two preceding studies with the reflection goniometer, those of Jenzsch and of Story-Maskelyne, as well as in our own study, has the full holohedral symmetry of the monoclinic system, that is, the symmetry of the normal class (C_{2h}).

The arrangement of the atoms in tenorite that reproduces the observed intensities is one in which the copper atoms occupy centers of symmetry and the oxygen atoms are situated on axes of symmetry. The coordinates of the copper atoms are $\frac{1}{4}, \frac{1}{4}, 0$; $\frac{3}{4}, \frac{3}{4}, 0$; $\frac{3}{4}, \frac{1}{4}, \frac{1}{2}$; $\frac{1}{4}, \frac{3}{4}, \frac{1}{2}$; the coordinates of the oxygen atoms are $0, n, \frac{3}{4}$; $0, \bar{n}, \frac{1}{4}$; $\frac{1}{2}, n+\frac{1}{2}, \frac{3}{4}$; $\frac{1}{2}, \frac{1}{2}-n, \frac{1}{4}$, where n, the parameter along the symmetry axis, has approximately the value, -0.08. The atoms are thus arranged in a four coordination, each oxygen being surrounded at approximately equal distances by four copper atoms on the corners of a non-equilateral tetrahedron and each copper atom being surrounded at approximately equal distances by four oxygens lying in a plane at the corners of a rectangle. The interatomic distance Cu-O is 1.9^+ Å, a value in good agreement with that predicted by M. L. Huggins for electron-pair bonded copper and oxygen in a four coordination. A decision as to whether the particles of cupric oxide are atoms or ions is not possible from the interatomic distance alone, however, since this distance is also in good agreement with that calculated, with the aid of V. M. Goldschmidt's curves of ionic radii, on the assumption that the crystal is composed of cupric and oxygen ions in a four coordination.

The structure of tenorite previously described by Niggli[7] was based on powder photographs only and is not correct. The conclusion of Kalkowsky[8] and of Niggli that tenorite is triclinic, pseudomonoclinic, is without foundation in experiment, and is erroneous. Niggli was apparently misled by the erroneous work of Kalkowsky; there is also the further extenuating circumstance for Niggli's failure to arrive at the correct structure that his conclusion was based on some very old powder photographs on which the crucial lines were probably missing. These lines are readily brought out, however, by the powerful radiation available today.

BOTANY.—*Two new grasses of the genus* Stipa *from Western United States.*[1] JASON R. SWALLEN, Bureau of Plant Industry.

Stipa latiglumis Swallen sp. nov.

Perennis; culmi graciles, erecti, 50–110 cm. alti, strigosi; vaginae pubescentes internodiis breviores; laminae planae 5–25 cm. longae, usque ad 3 mm. latae, supra pilosae, subtus glabrae; ligula 1–4 mm. longa; panicula 15–30 cm. longa, ramis gracilibus appressis usque ad 10 cm. longis; glumae subaequales 12–15 mm. longae, 3 mm. latae, firmae, acutae vel acuminatae, 3-nerves; lemma 8–9 mm. longum, dense pilosum, callo 1 mm. longo pungenti, arista bigeniculata plumosa.

Fig. 1

Fig. 2

Fig. 1.—*Stipa latiglumis*, floret ×5 dia. and nat. size. From type specimen.
Fig. 2.—*Stipa lobata*, floret ×5 dia. and nat. size; summit of floret showing lobe ×10 dia. From type specimen.

[7] Zeit. f. Krist., 57: 253. 1922.
[8] Zeit. Kryst. Min., 3: 279. 1879.
[1] Received January 17, 1933.

Perennial; culms slender, erect, 50–110 cm. tall, strigose below, nearly smooth above; sheaths, at least the lower, pubescent, shorter than the internodes; blades flat or loosely involute, 5–25 cm. long, not more than 3 mm. wide, hairy on the upper surface, smooth on the lower; ligule membranaceous 1–4 mm. long; panicles loosely flowered, 15–30 cm. long, hairy in the axils, the branches distant, slender, the lower ones as much as 10 cm. long; glumes about equal, 12–15 mm. long, 1.5 mm. broad from keel to margin, firm, rather abruptly acute or acuminate, 3-nerved, tinged with purple; lemmas 8–9 mm. long, densely hairy, the sharp callus 1 mm. long, the awn 3.5–4.5 cm. long, twice bent, the first two segments twisted, plumose, the third straight, scabrous, or pubescent below.

Type in the U. S. National Herbarium no. 992334, collected at Camp Lost Arrow, Yosemite Valley, California, altitude 4,000–4,500 feet, June 22, 1911, by LeRoy Abrams (no. 4469).

Specimens of *Stipa latiglumis* have been referred previously to *S. californica* Merr. & Davy and to *Stipa elmeri* Piper & Brodie. From the first it differs in having pubescent culms and sheaths, and longer, more plumose awns, from the second in the usually less dense pubescence, and from both in having firmer, broader, purplish glumes and longer lemmas. In *S. californica* the culms and sheaths are glabrous and the awns are 2.5–3.5 cm. long; the pubescence of *S. elmeri* is conspicuous without a lens, but that of *S. latiglumis* is scarcely evident except with a lens; and in both *S. californica* and *S. elmeri* the glumes are thin, pale, and not more than 1 mm. wide from keel to margin, and the lemmas are only 6–7 mm. long.

Central California, at medium altitudes.

Yosemite Valley: *Bolander* 6099, *Abrams* 4469, *Jepson* 4280; Dunlap to Millwood, *Griffiths* 4680.

Stipa lobata Swallen, sp. nov.

Perennis; culmi dense caespitosi, erecti, 35–85 cm. alti, glabri, infra paniculam scaberuli; vaginae internodiis longiores, scaberulae, marginibus pilosis; laminae basi planae, attenuatae, usque ad 50 cm. longae, basi 1–4 mm. latae, supra scabrae, subtus laeves; ligula 0.5 mm. longa; panicula 10–18 cm. longa, ramis appressis multifloris; glumae subaequales, acuminatae, 9–10 mm., raro usque ad 12 mm., longae, 3-nerves; lemma 6 mm. longum, dense pilosum, lobatum, callo obtuso; arista bigeniculata, 12–16 mm. longa, hispida.

Perennial; culms densely tufted, erect, 35–85 cm. tall, glabrous, scaberulous below the panicle; sheaths longer than the internodes, or the upper ones shorter, scaberulous, the margins sparsely pilose; blades flat or loosely folded toward the base, long-attenuate to a fine involute tip, as much as 50 cm. long, 1–4 mm. wide at the base, scabrous on the upper surface, nearly smooth beneath; ligule less than 0.5 mm. long; panicles 10–18 cm. long, the branches appressed, rarely more than 5 cm. long, several-flowered; glumes subequal, or the first a little longer, acuminate, 9–10 mm., the second sometimes as much as 12 mm., long, both 3-nerved, scabrous; lemma 6 mm. long, brownish, evenly densely hairy, the hairs 1–2 mm. long, the callus very short and blunt, the summit 2-lobed, the lobes 0.8–1.5 mm. long, awned from between the lobes, the awn 12–16 mm. long, twice bent, the first two segments twisted, appressed hispid, the third segment straight, scabrous.

Type in the U. S. National Herbarium no. 905722, collected on a rocky hill, Ranger Station, Queen, Guadalupe Mountains, New Mexico, altitude

6,000–7,000 feet, September 3–6, 1915, by A. S. Hitchcock (Amer. Gr. Nat. Herb. no. 819).

This species has been referred to *Stipa scribneri* Vasey, but differs in having shorter, nearly equal glumes, which are prominently scabrous, shorter awns, and shorter, lobed lemmas, which are evenly hairy all over. In *S. scribneri* the glumes are unequal, the first about 10 mm., the second 15 mm. long, scaberulous, the awns are 17–20 mm., the lemmas are 7–9 mm. long, the lobes of which are less than 0.5 mm. long, and the hairs at the summit are 2 mm. long, conspicuously longer than those on the body.

Rocky hills at medium altitudes, southern Texas and New Mexico.

TEXAS: Chisos Mountains, *Moore & Steyermark* 3362; Guadalupe Mountains, *Moore & Steyermark* 3638; without locality, *Nealley*.

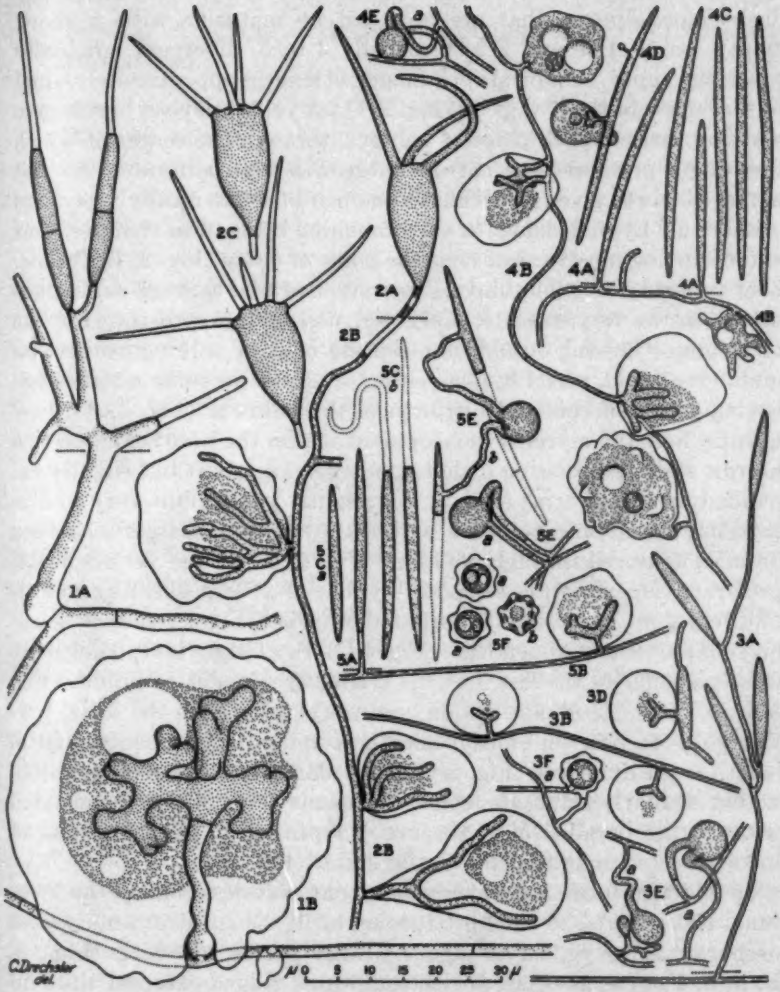
NEW MEXICO: Guadalupe Mountains, *Amer. Gr. Nat. Herb.* no. 819; Filmore Canyon, Organ Mountains, *Hitchcock* 3773.

BOTANY.—*Morphological features of some fungi capturing and killing amoebae.*[1] CHARLES DRECHSLER, Bureau of Plant Industry.

Amoebae developing in agar plate cultures started from plantings of diseased rootlets and other decaying plant materials were found to be captured and killed often in large numbers by various fungi.[2] A protozoan of large size identified provisionally as *Amoeba verrucosa* was preyed upon by a fungus distinguished by rather short, somewhat tapering, sparingly branched, noticeably but not markedly differentiated conidiophores bearing elongated 2-celled conidia, the latter individually having an empty third cell present as an apical appendage nearly equal in length to the two living cells taken together (Fig. 1, A). Capture was effected by the animal being held fast on short, rather globose, ultimately somewhat yellowish adhesive protuberances borne laterally on prostrate superficial hyphae. At the place of contact the animal's pellicle was soon perforated and a somewhat expanding hyphal outgrowth thrust toward the center of the host where through close successive dichotomous branching in three planes (Fig. 1, B) a fairly intricate complex of swollen elements was produced, which though at first continuous, later with the exhaustion of the protoplasm of the host, became closely septate. A smaller amoeboid organism was captured through adhesion to the prostrate, narrow, non-septate, superficial hyphae of a fungus bearing on short undifferentiated aerial hyphal branches or on short, undifferentiated,

[1] Received March 10, 1933.

[2] Detailed descriptions and taxonomic discussion of these forms are reserved for a more comprehensive account of predacious fungi which is in preparation.



Figs. 1–5.—Various amoeba-capturing fungi, each numeral denoting a separate species, all drawn with the aid of the camera lucida at the same magnification; ×1000. A, Conidiophore or conidiophorous hypha, the proximal beginning of the aerial part being indicated by a heavily dotted line. B, Captured amoebae adhering to prostrate filament, mostly with development of fungus within. C, Detached conidia. D, Conidium with germ tube directly invading animal host. E, Sexual apparatus showing union of oogonium and antheridium, these being borne on (*a*) mycelial branches or on (*b*) germ tubes. F, Mature oospores with enveloping oogonial walls, shown (*a*) in optical section and (*b*) in surface aspect.

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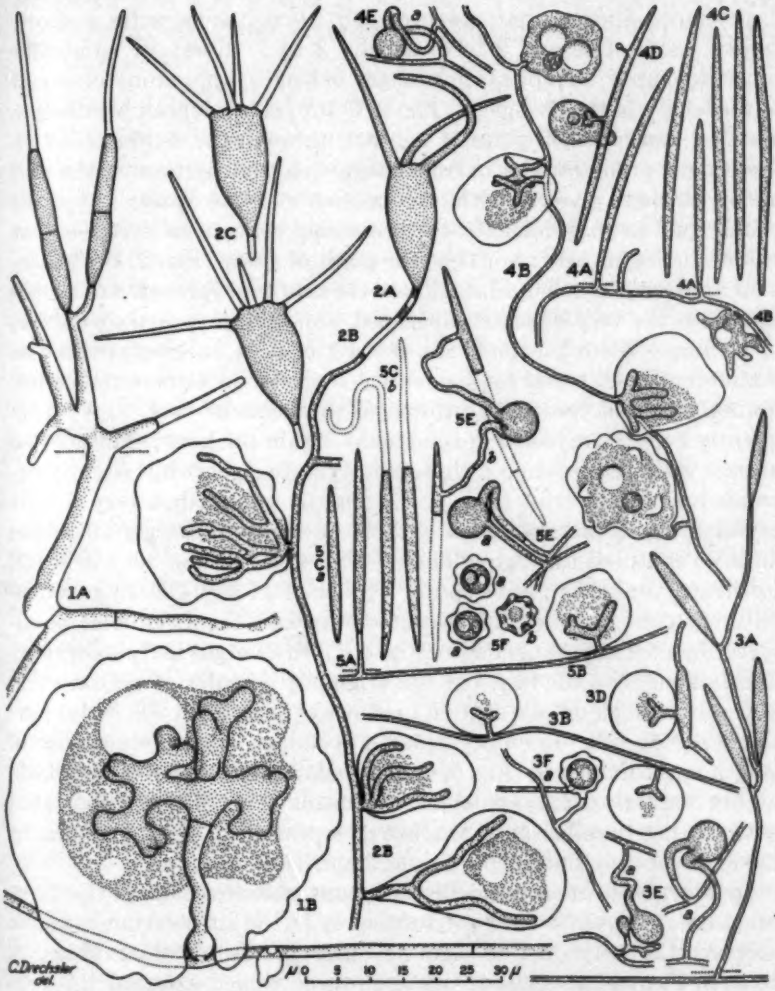

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aerial prolongations of prostrate hyphae (Fig. 2, A) 1-celled inversely flask-shaped spores, that are provided at maturity with a short, empty, basal stipe and 2 to 6, usually 3 to 5, divergent, gradually tapering, empty, subapical appendages, of lengths approximately equal to the length of the living cell (Fig. 2, C.) A yellow deposit of adhesive material marked each place of contact, through the center of which the fungus proliferated a narrow outgrowth that perforated the animal's pellicle to give rise within to an open bushlike ramifying system of subequal hyphal elements, the branching being of moderate extent and occurring mostly at or near the point of entry (Fig. 2, B). Amoeboid animals of smaller dimensions were captured through similar adhesion on the very delicate, superficial, non-septate, prostrate hyphae of a fungus bearing fusoid, non-septate conidia on erect, otherwise undifferentiated, aerial hyphae either singly or in some number following repeated continued growth of the filament (Fig. 3, A). Frequently here the mycelial development within the host is limited to a narrow stalk terminating dichotomously in two short but slightly expanded divergent arms (Fig. 3, B). Slightly greater but very similar mycelial development occurs within the somewhat larger amoeboid animals captured through adhesion (Fig. 4, B) on the very delicate, prostrate, superficial, non-septate hyphae of a fungus bearing on usually very short, erect, undifferentiated branches (Fig. 4, A) aerial, acicular conidia without appendages (Fig. 4, C). In a fungus morphologically closely similar to the last, but the originally acicular conidium (Fig. 5, C, *a*) of which on maturation becomes evacuated in the distal portion so as to bear an empty apical appendage often about equal in length to the living cell (Fig. 5, C, *b*), similar development of mycelium within similarly small amoeboid organisms (Fig. 5, B) is associated with further parallelism in absence of septation in the mycelium, in mode of capture and in sporulating habit (Fig. 5, A).

In addition to their decidedly caducous, colorless conidia the three fungi last referred to each produce on or in the substratum a yellow oospore, the polygonal or sigillate outer profile of which (Figs. 3, F, *a*; 5, F, *a*) is associated with sculptured ridged external thickenings of the oospore wall (Fig. 5, F, *b*). This oospore in all three species is produced through the fertilization of a terminal globose oogonium by a slightly expanded terminal antheridium borne on a branch arising from a neighboring hypha (Figs. 3, E, *a*; 4, E, *a*; 5 E, *a*). Not infrequently the germ tube from a conidium gives rise rather directly to a sex organ (Fig. 5, E, *b*), just as in other instances it very directly penetrates a host animal (Figs. 3, D; 4, D).

BOTANY.—*A new disease of dahlias.*[1] THELMA BENNETT POST,[2] Bureau of Plant Industry. (Communicated by CHARLES DRECHSLER.)

Diseased dahlia stems received from Columbia, South Carolina, on July 29, 1932, bore both the pycnidial and sclerotial[3] stages of *Macrophomina phaseoli* (Maubl.) Ashby (1).[4] The specimens consisted of thick sections of stem from near the base. Most of the stem tissue was blackened, but some green water-soaked tissue was still evident. The pycnidia occurred in great numbers in the epidermis of the blackened areas. As the stem tissue dried, the fibers separated easily and the ends were split and frayed. Most of the pith had disappeared, leaving only a thin brittle remnant in which the sclerotia were imbedded in such profusion that it had the appearance of a black crust. No pycnidia were observed in this remnant and the sclerotia were not found elsewhere.

THE PYCNIDIA IN CULTURE

Sections of the leaf petioles, the stem, and the patch of green tissue remaining on the dahlia stem were planted after surface sterilization on acid corn meal agar and after three days sclerotia became visible to the unaided eye. No pycnidia appeared in these cultures. On the other hand, mature pycnidia of *Macrophomina phaseoli* appeared in a culture secured from sections of the tissue containing sclerotia eighteen days after the planting was made. This culture was on an acid corn meal agar plate and the appearance of pycnidia was preceded by abundant development of sclerotia (Fig. 7).

Spores from the pycnidia produced in culture were observed to germinate readily on potato dextrose agar and in a 2 per cent dextrose solution in sterilized tap water (Fig. 8). On the other hand, when spores from the pycnidia found on the host were planted on various media, i.e., corn meal, potato dextrose, and string bean agar, no germination occurred, although repeated trials were made. Small (2), who tried unsuccessfully to germinate the spores of pycnidia found among sclerotia of *Rhizoctonia bataticola*, attributed the failure to the fact that the trials were made two years after the material was collected and that the spores were therefore too old. The pycnidia and

[1] Received January 3, 1933.
[2] The writer is indebted to Dr. Freeman Weiss for assistance in preparation of the paper and to Dr. L. L. Harter and Miss Vera K. Charles for criticism and suggestions.
[3] Commonly designated as *Rhizoctonia bataticola* (Taub.) Butler.
[4] Identification suggested by Vera K. Charles.

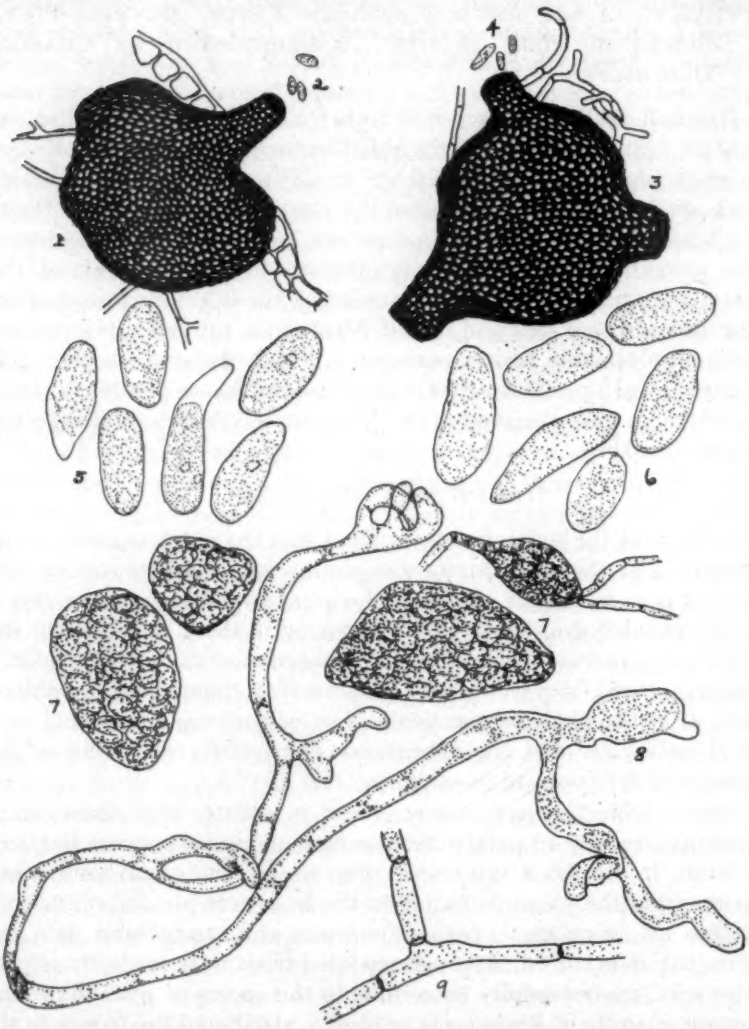

Fig. 1.—Pycnidium of *Macrophomina phaseoli* from dahlia tissue, (×200). Fig. 2.—Spores from above pycnidium, (×200). Fig. 3.—Pycnidium of same from culture (Leonian malt agar) showing development of several ostioles, (×200). Fig. 4.—Spores from above pycnidium, (×200). Fig. 5.—Spores from pycnidium on host, (×950). Fig. 6.—Spores from pycnidia of culture on dahlia stem. (×950). Fig. 7.—Sclerotia from culture on corn meal agar, (×200). Fig. 8.—Spore germinated in sterile tap water plus 2% dextrose. Drawn eighteen hours after being placed in the solution, (×950). Fig. 9.—*M. phaseoli* mycelium taken from culture on bean plug, (×950). All figures drawn with the aid of the camera lucida.

spores from the dahlia material were young and their failure to germinate in the writer's cultures could not be attributed to age.

Cultures were later made from the fibrous roots of the dahlia and the sclerotium-bearing fungus was recovered. No pycnidia developed in these cultures.

Spores from the pycnidia obtained in culture were placed in the liquid of tubes containing steamed dahlia stems. The stem was soon overgrown with mycelium, and mature pycnidia appeared five days after the inoculation (Fig. 6). Pieces of epidermis from these stems were planted on plates of various media, i.e., Leonian malt-agar, potato dextrose, corn meal, and string bean agar. On each medium pycnidia and sclerotia developed (Fig. 3). Spores were placed in the liquid of tubes containing sweet clover stems, sunflower stems, and string bean plugs. In each of these the fungus grew rapidly and produced numerous sclerotia, but no pycnidia appeared. As remarked by Haigh (3), "it is evident that a particular set of conditions . . . is necessary for their production."

The production of the pycnidia in culture is noteworthy, as they have only been recorded twice. Haigh (3) reported the occurrence of six or eight pycnidia of *Macrophomina phaseoli* in a culture of the so-called *Rhizoctonia bataticola* (Taub.) Butl. This culture was on maize meal, and was grown from a single spore of *M. phaseoli* obtained from beans affected with "ashy stem blight." The culture was so old that it was drying out at the edges. These pycnidia were larger and more elongated than those he had found in nature. Single spore cultures from these pycnidia always gave rise to pure growths of the fungus *Rhizoctonia bataticola*. There was no further report of the pycnidia in culture until in 1930, when Haigh (4) again obtained them. This time they were produced in a strain of the *Rhizoctonia bataticola* isolated from *Cajanus indicus*. Spores and sclerotia continued to produce pycnidia and sclerotia in culture, and Haigh regarded the strain as a saltant from the original culture of *R. bataticola* from *Cajanus*.

Whether the *M. phaseoli* reported in this paper arose as a saltant from the sclerotial fungus or from mycelium that may have been present among the sclerotia in the tissue from which the plates were made is not evident.

Three plates were made in the same manner from similar pieces of sclerotium-bearing tissue, but in only one did pycnidia appear. Furthermore, as pointed out earlier in this paper, pycnidia were observed only in the epidermis of the dahlia stem and not in the remnant of the pith where the sclerotia appeared. The rare occurrence of

the pycnidia in culture, despite the numerous cultures made by various workers over a period of several years, would seem to indicate saltation as the most tenable theory.

SINGLE SPORE CULTURES

Single spores grown on corn meal, beef, and potato dextrose agar gave rise to pure cultures of the sclerotium-bearing fungus and a fungus that produced both sclerotia and the pycnidial stage of *Macrophomina phaseoli*. The cultures producing pycnidia have been transferred and retransferred and have continued to produce pycnidia and sclerotia. The single spore cultures that produced the sclerotium-bearing fungus have also been transferred and retransferred, and no pycnidia have appeared in them.

DESCRIPTION OF THE FUNGUS

The pycnidia found in the epidermis of the dahlia stem in nature (Fig. 1) were 171–198μ in diameter and the spores (Fig. 2 and Fig. 5) were 18–25μ×7.2–9μ. These dimensions compare with the pycnidial dimensions of *Macrophomina phaseoli* (Maubl.) Ashby,[5] which are given (1) as mostly 100–200μ in diameter, and for the spores as 20–30μ×8–10μ. The thin-walled angular cells described by Ashby (1) are plainly visible in the young, immature pycnidium. The pycnidia became black and carbonaceous with age. The pycnidia on potato dextrose agar are 136–200μ and the spores are 18.2–28μ×7.2–10.8μ.

The sclerotia found in the pith in nature were 62μ to 117μ in diameter, while on potato dextrose agar they ranged from 40 to 80μ in diameter. Ashby (1) gives the sclerotial dimensions of *M. phaseoli* as 50–100μ in diameter in the tissues of herbaceous plants and as having the same dimensions in culture. He adds that Small found them up to 0.8 to 1 mm. in diameter in the roots of woody plants.

Haigh (4) separates the sclerotial forms of *Rhizoctonia bataticola* into three strains according to their mean sclerotial diameter. "As far as is known at present," he writes, "the pycnospores of *Macrophomina phaseoli*, from whatever source they were isolated, have always given in culture sclerotia which belong to the lowest of these groups." This, he believes, accounts for Ashby's remark that in cultures the variation of the sclerotia of *M. phaseoli* is 50 to 200μ. Haigh believes that it may be found that the two large sclerotial strains (A and B) have no connection with *M. phaseoli*. The size of the sclerotia from the dahlia tissue and of the spores from monosporous cultures, as reported

[5] The taxonomic position of the fungus is not clear and further study on this subject is intended.

in this paper, places them in strain C of Haigh's classification and further bears out his theory regarding the connection between that strain and *M. phaseoli*.

The pycnidia produced on the culture media displayed a tendency to form several ostioles, as many as four being found on one pycnidium. The pycnidia were also of greatly variable shapes and sizes. Those formed on the steamed dahlia stems appeared to be like those formed in nature, with single ostioles. They were produced abundantly and were filled with pycnospores. In no case was evidence of a stromatic origin found.

TAXONOMY OF THE FUNGUS

In 1904, D'Almeida and da Camara (5) found a *Macrophoma* on the branches of *Dahliae variabilis* Desf., in the Coimbra botanical garden in Portugal, which they named *Macrophoma henriquesiana*. They gave the diameter of the pycnidia as 140–190μ and the spore dimensions as 17–23μ×5–8μ. Although the spore measurements are slightly smaller than those given for *Macrophomina phaseoli* (20–30μ ×8–10μ), they are essentially the same, and the descriptions in other particulars tally. The drawings of the spores of *Macrophoma henriquesiana* are suggestive of those of *Macrophomina phaseoli* (Maubl.) Ashby. Ashby (1) has pointed out that variations in spore size on the same host may be considerable. Shaw (6) gave for them, as a maximum range on jute in India, 16–29μ×6–11μ and Sawada (7) for the same host in Formosa gave the spore dimensions as 16–23μ×7–10μ. It thus appears probable that *Macrophoma henriquesiana* d'Alm. & da Cam. is identical with *Macrophomina phaseoli* (Maubl.) Ashby and should be added to the list of synonyms.[6]

Small (2) found the sclerotia of *R. bataticola* in the roots and stems of dahlias in Ceylon, but does not report having found the *Macrophomina* stage in these plants. The sclerotia also developed on the skin of dahlia tubers that appeared to be healthy, but whose roots and stems were diseased.

A fungus disease of dahlias called "black blight" is mentioned but not identified in a list of Scottish fungus diseases published by Alcock and Foister (8) in 1931.

[6] The synonyms as given by Ashby (1) are: *Macrophoma phaseoli* Maubl. (1905), *Sclerotium bataticola* Taub. (1913), *Macrophoma corchori* Saw. (1916), *Macrophoma cajani* Syd. & Butl. (1916), *Macrophomina phillipinensis* Petr. (1923), *Rhizoctonia lamellifera* Small (1924), *Rhizoctonia bataticola* (Taub.) Butl. (1925), *Dothiorella cajani* Syd. & Butl. (1925), *Macrophoma sesami* (1922).

ETIOLOGY

The conditions of infection of the dahlia by *Macrophomina phaseoli* are not known. The tubers which produced the dahlia stems studied were new stock purchased from four separate firms. They were planted in a site that had been used as a vegetable garden for years, but there is no record of these vegetables having been diseased. At the present time there are vegetables growing in close proximity to the dahlias and these appear to be healthy. The dahlias grew and flowered in normal fashion until July, when the disease appeared. All the plants (about three dozen) were affected.

Ashby (1) asserts that the parasitism of *Macrophomina phaseoli* appears to be much influenced by the effect of environmental and nutritional conditions on the host. Haigh (4) concludes from his experiments that special conditions are required for successful inoculation with the fungus called *R. bataticola*, whose connection with *M. phaseoli* has been demonstrated.

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PALEOBOTANY.—*A new* Lygodium *from the late Tertiary of Ecuador.* Edward W. Berry, Johns Hopkins University.[1]

Among the large amount of material from the Loja basin in southern Ecuador which I owe to the industry of Professor Clodoveo Carrión of Loja there occurs sparingly small pinnules of the genus *Lygodium* Swartz of the fern family Schizaeaceae.

This represents a species which is obviously new and which differs considerably from any known species either existing or fossil. It is, however, based entirely on detached pinnules and this fact in conjunc-

[1] Received January 30, 1933.

tion with the further fact that the existing species are sadly in need of modern treatment renders a wholly adequate discussion of the fossil impossible. The latest account of the family with which I am familiar, that by L. Diels in 1902 in "Die Natürlichen Pflanzenfamilien," in so far as the genus *Lygodium* is concerned, is largely based on K. Prantl's discussion of the genus in 1881. Nearly all of the modern species are very variable and in looking over herbarium material one gets the impression, perhaps a superficial one, that the specific limits of many of the species are illy understood.

The present fossil form may be named *Lygodium bifidum* and may be briefly characterized as follows: Pinnules small, consisting of two principal lobes and an incipient basal lobe on either side. In the limited amount of material at my disposal the fertile pinnules are not much more than half the size of the sterile pinnules, as may be seen in Figs. 1–3. Both are slightly inequilateral in that one of the principal lobes is somewhat longer and it may also be somewhat broader than its fellow. If the figured specimens can be considered as typical, they show the following feature. Pinnules sessile. Base broad varying from nearly truncate and but slightly excavated in the sterile pinnule, to considerably excavated and almost cordate in the fertile pinnule. In the latter the length of the lobes from the point of attachment

Figs. 1–3. Pinnules of *Lygodium bifidum* Berry n.sp. from the late Tertiary of Ecuador. Fig. 1. Drawing of fertile pinnule ×2. Fig. 2. Photograph of fertile pinnule ×2. Fig. 3. Sterile pinnule ×2.

is 1.75 cm. and 2 cm.; the two main veins diverge at the base at an angle slightly less than 50°, at first recurving slightly and then incurving so that the tips are 1.75 to 2.0 cm. apart. In the former the length of the corresponding lobes is 2.75 cm. and 3.5 cm., the two main veins diverge at the base at an angle of about 55° and recurve so that their tips are 4 cm. or more apart. In both it is the right lobe that is longest, and in both the right basal lobule appears to be somewhat more developed than the left. The substance is not delicate at all but appears from the manner of preservation to be much thinner and much less coriaceous than in many of the existing species. The margin is entire or slightly crenulated. A single stout vein enters the base of the pinnule, but this immediately breaks up into two main forks and subsidiary branches which supply the basal lobules. The main branches are stout, prominent and flexuous, giving off alternately stout laterals which diverge at acute angles and fork once or twice as they recurve outward to the margins.

The fertile pinnules have a double row of thick sporangia preserved at intervals along the margins. These are incompletely preserved as partial cavities, but their nature is obvious and their appearance convincing, although I have been unable to find spores.

I have been unable to find any closely similar forms among existing species. Those with a bifid habit are extremely rare. There is some resemblance to *Lygodium cubense* H.B.K. of the larger Antilles but the latter has larger pinnules with more elongated lobes and more oblique veins, although no other living species that I have seen is as similar as some of the pinnules of this species, which is a highly variable one, however, and the resemblance is really not very close. There are perhaps 25 existing species most of which are tropical, although the eastern American species *L. palmatum* extends well into the Temperate Zone as does *L. japonicum* Swartz in Japan and *L. articulatum* in New Zealand. The genus is represented at the present time on all of the continents except Europe and is represented in equatorial America from Mexico through Central America and the Antilles to northern South America. So far as I know it is not found in Ecuador or Peru west of the eastern slopes of the Andes, but this enormous region has been but superficially explored botanically so that no one can foresee what a detailed knowledge of it would disclose.

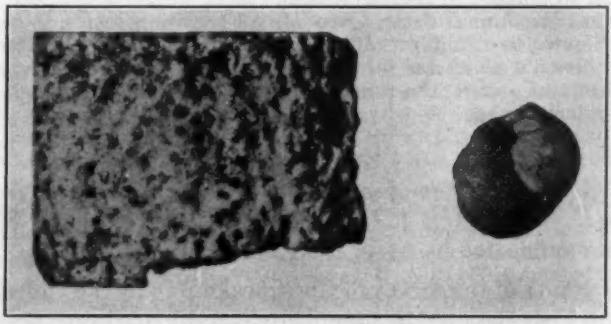
About 25 fossil species have been described but many of these are very incompletely known and are based upon very superficial differences in the form of the sterile pinnules. Supposed species are recorded from the middle Cretaceous in both America and Europe. From the beginning of the Eocene onward *Lygodium* is well represented in both America and Europe but is unknown in the United States after the Oligocene and in Europe after the Miocene. The bulk of the fossil material is of the *palmatum* type and much of it shows fruiting pinnules.

PALEONTOLOGY.—*A new species of Hydrocorallinae from the Pleistocene of New Jersey.*[1] HORACE G. RICHARDS, University of Pennsylvania. (Communicated by C. E. MCCLUNG.)

While holding a Harrison Fellowship at the University of Pennsylvania (1929–30, 1930–31), I was able to do considerable collecting in the Pleistocene deposits of New Jersey. In carrying on this work I was greatly aided by a grant from the University of Pennsylvania chapter of the Society of Sigma Xi. A complete report upon this material is forthcoming. Among this material were some very worn specimens of Hydrocorallinae (Hydrozoa) which represent a new species. Most of the material upon which the forthcoming report is based was obtained from fill from hydraulic dredging usually pumped from 30 to 55 feet below the bottom of thorofares and inlets lying back of the coastal islands of New Jersey. A large part of the material thus obtained was fossil and has been referred to the Cape May Formation which underlies these coastal islands.

Description. Polyparium encrusting on shells of gastropod mollusks; the incrustation is of one or more layers and is usually about 1 mm. or less in thickness. As far as can be observed the shell is not absorbed by the coral. On the surface at irregular intervals are distributed thick-lipped pores, the mouths of which are irregularly stellate; pseudo-septa are well marked and are usually about six in number, although variations from four to seven have been noted. The pores are not elevated above the surface of the colony; the opening between the septa is often very narrow. The average diameter of these stellate pores is 0.2 mm.

No other sets of pores can be clearly observed, although faint indications of other pores, probably round and larger than the stellate pores, can be



Milleaster interglacialis n. sp. Fig. 1.—Type, magnified 8 times. Fig. 2.—Paratype, natural size.

[1] Received December 12, 1932.

seen on a portion of the type specimen. All the material collected is very worn, and it is therefore impossible to describe the species more fully and to ascertain the relationship of the form. It resembles *Milleaster incrustans* Ulrich[2] from the Miocene of Maryland in general appearance and in the structure of the stellate pores and pseudo-septa, but differs from it in having fewer pores and in not having them elevated; it also differs from the Miocene form in the absence (or inconspicuousness) of two other sets of pores. In *M. incrustans* there is a set of pores, fewer in number than the stellate pores, which occupy the spaces between the stellate apertures; these are a little larger than the stellate pores and are irregular in shape. In the Miocene form there is also a set of very small pores scattered among the granules of the interspaces. It is possible that pores comparable to either or both of these sets were present in the New Jersey specimens, but are not visible because of the worn condition of the material.

Ulrich places another Miocene species tentatively in the genus *Milleaster*. *Milleaster* (?) *subramosus* Ulrich[3] also from Maryland consists of a series of stellate pores somewhat resembling those of *M. incrustans*. The larger of the sets of non-septate pores has not been observed, but the smaller set is well represented. As the main argument for placing this form in the genus *Milleaster*, Ulrich relies on the presence of the septate pores. This same argument might be used for placing the Pleistocene species, *Milleaster* (?) *interglacialis* tentatively in that genus also.

Type locality. Two Mile Beach, Cape May County, New Jersey; material obtained from hydraulic fill pumped from 30–55 feet below the bottom of the thorofare back of the island. (Collector, Horace G. Richards.)

Occurrence. Cape May Formation. Two Mile Beach; Holliday Beach (Stone Harbor), New Jersey.

Collection. The type and two additional specimens have been presented to the United States National Museum (type, catalogue number 371911; additional specimens, 371912, 371913).

Remarks. The fauna of the Cape May Formation seems to indicate a milder climate than that prevailing on the New Jersey coast to-day. Because of this mild fauna and for stratigraphic reasons discussed at length in the forthcoming report, the formation has been dated as belonging to the last interglacial stage.

ZOOLOGY.—*A new amphipod of the genus* Amphiporeia *from Virginia.*[1] CLARENCE R. SHOEMAKER, U. S. National Museum. (Communicated by M. J. RATHBUN.)

In the course of the survey of Chesapeake Bay by the United States Bureau of Fisheries in 1916 a number of amphipods were taken on the

[2] Maryland Geological Survey, Miocene (1904) p. 436.
[3] Loc. cit. p. 437.
[1] Published by permission of the Secretary of the Smithsonian Institution. Received January 12, 1933.

beach between tide marks at Virginia Beach, Virginia. Upon study they appear to belong to the genus *Amphiporeia* which was first taken at Grand Manan, Bay of Fundy, by Dr. Mary J. Rathbun in 1898, and later by the Cheticamp Expedition in 1917 in the Gulf of St. Lawrence. The specimens from Virginia Beach are quite distinct from the northern species, *A. lawrenciana*,[2] and I now propose the name *Amphiporeia virginiana* for this new species.

The species appears to be very abundant as a large number of specimens were taken, but males apparently are rare, not one having been detected.

Amphiporeia virginiana n. sp.

Description of the female.—Body compressed. Eye small, oval, black. Lateral angle of head evenly rounded. Antenna 1 in the normal deflected position reaching to about the middle of the fifth joint of antenna 2, the geniculation between the first and second joints not very pronounced; first joint robust, about twice as long as high, second and third joints short and subequal in length, flagellum shorter than peduncle and composed of 6 joints, the 2-jointed accessory flagellum about equal in length to the first joint of the primary flagellum. Antenna 2, flagellum shorter than fourth and fifth peduncular joints combined and composed of 7 joints, the first joint of the flagellum being much longer than the succeeding joints and probably representing a fusion of several joints; second peduncular joint with gland-cone small, fourth joint more robust but slightly shorter than fifth. Mandible with cutting edge narrow and bearing several small teeth, accessory cutting plate well developed, 5 spines in spine row, molar prominent and strong and bearing a plumose seta on upper edge, base of molar toward spine-row bearing a small toothed seta and also a small flat tooth with upper truncate, serrate cutting edge, first joint of palp short, second joint very broad and a little longer than third with front margin very convex and densely armed with long slender spines, rear margin slightly convex and bearing a few slender spines, third joint half the width of second and having the distal half of the outer margin densely armed with long slender spines, rear margin also bearing several groups of long slender spines. Maxilla 1 much as in *A. lawrenciana*, inner plate broad and bearing 11 plumose marginal setae, outer plate very obliquely truncate and bearing 11 spine-teeth; palp, second joint broad with 7 spine-teeth and 7 slender setae on rounding apex. Maxilla 2 as in *A. lawrenciana*. Lower lip with lobes short and broad, mandibular processes short and broad, inner lobes well developed. Side-plate 1 very slightly bent forward. Gnathopod 1, sixth joint only slightly shorter than fifth and nearly as wide as long, palm oblique and curving into hind margin of joint without defining angle or defining spines. Gnathopod 2, sixth joint about two-thirds as long as fifth and about two-thirds as wide as long, palm oblique and without defining angle or defining spines, but provided throughout with a lamellar, finely serrate cutting edge. Peraeopods 1 and 2 subequal in length and proportionally alike. Side-plate 4 with shallow emargination on upper hind margin. Peraeopod 3, first joint nearly as long as second, which is nearly as wide as long, fourth joint broadly oval and

[2] Contrib. Canadian Biol. and Fisheries, 5: no. 10, p. 248. 1929.

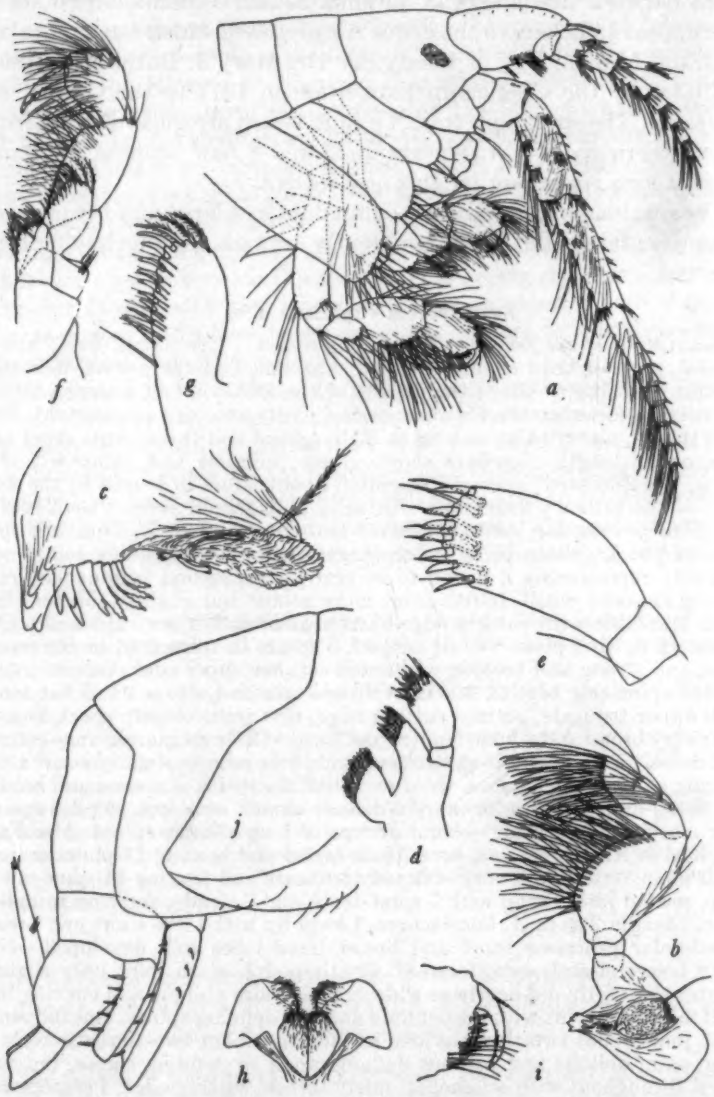


Fig. 1. *Amphiporeia virginiana*, new species. Female, *a*, Anterior part of animal. *b*, Mandible. *c*, Molar, cutting plates and spine row of mandible much enlarged. *d*, Maxilla 1. *e*, Palp of maxilla 1 enlarged. *f*, Maxilliped. *g*, Outer plate of maxilliped enlarged. *h*, Lower lip. *i*, Distal end of gnathopod 2 enlarged.

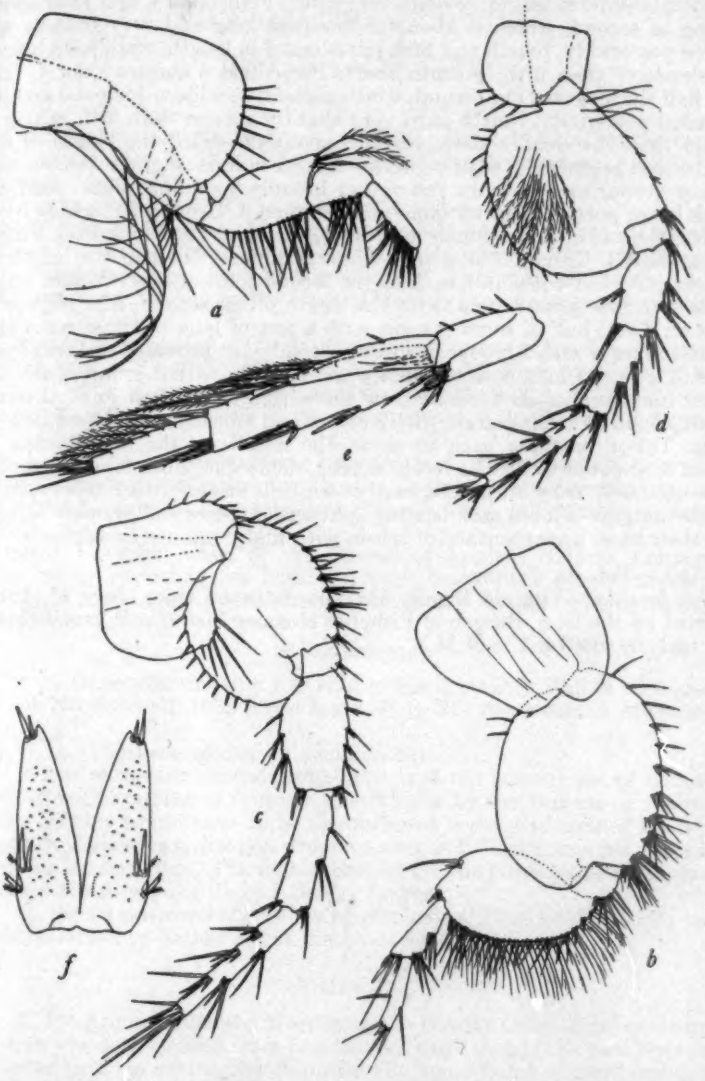


Fig. 2. *Amphiporeia virginiana*, new species. Female, *a*, Peraeopod 2. *b*, Peraeopod 3. *c*, Peraeopod 4. *d*, Peraeopod 5. *e*, Uropod 3. *f*, Telson.

armed on front margin with many long slender spines and setae, fifth and sixth joints equal in length, seventh very short. Peraeopod 4, first joint about as long as second, which is about as broad as long and very broadly expanded posteriorly, fourth and fifth joints equal in length, sixth joint longer and slenderer than fifth, seventh short. Peraeopod 5 shorter than 4, first joint half the length of the second, which is about as wide as long and greatly expanded posteriorly, fourth joint very slightly shorter than fifth, which is shorter than the slender sixth, seventh about one-third the length of the sixth. Pleon segment 3 with posterior lateral margin slightly convex and lower posterior angle evenly and rather broadly rounding. Pleon segment 2 with lower posterior corner more angular than 3. Uropod 2 reaching back as far as the end of the peduncle of uropod 3. Uropod 1 reaching back a little farther than 2. Uropod 3 long and slender, peduncle one-half the length of the first joint but equal in length to the second joint of outer ramus, outer ramus with first joint nearly twice the length of the second, first joint provided on distal half of inner margin with a row of long plumose setae and on outer margin with 2 groups of spines, second joint provided on inner margin with a row of long plumose spines and apically with a group of slender spines; inner ramus about two-thirds the length of the first joint of outer ramus, armed on inner margin with 3 spines and apically with 2 long slender spines. Telson reaching back to about the middle of the inner ramus of uropod 3, about two-thirds as wide as long, dehiscent, lobes tapering gently to the obliquely truncate apices, each of which is armed with 2 short spines, outside margins of lobes each bearing 2 groups of spines and plumose setules near their base, upper surface of telson with many minute tubercles.

Length.—Female, 7.5 mm.

Type locality.—Virginia Beach, Virginia, between tides, July 17, 1916, collected by the U. S. Bureau of Fisheries steamer *Fish Hawk;* female holotype (cat. no. 66074, U.S.N.M.).

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

BOTANICAL SOCIETY

243RD MEETING

The 243rd regular meeting was held in the Assembly Hall of the Cosmos Club on October 4, 1932. Vice-president CHARLES BROOKS presided; attendance about 85.

KNOWLES A. RYERSON was elected to membership.

Brief notes and reviews: M. B. WAITE exhibited a specimen of Maryland mammoth tobacco about nine feet high which does not bloom in Maryland unless protected from frost in a greenhouse. This plant led to the studies of GARNER and ALLARD on the effect of length of day upon plants. Discussed by R. F. GRIGGS.

The summer meetings of the American Association for the Advancement of Science held in Syracuse, New York, June 20–25, were reported by R. F. GRIGGS and N. R. SMITH; the former discussing the program of the Botanical Society of America, and the latter, the program of the Society of American Bacteriologists.

H. L. SHANTZ, President of the University of Arizona and a former member of the Society was called upon by the Chairman for a few remarks.

Program: JAMES A. FARIS:—*Agriculture in Cuba.* (Illustrated by lantern slides.)

Doctor VAVILOV, Chief of the Bureau of Applied Botany, Leningrad, spoke briefly regarding the botanical work being done by the Soviet, especially in sending out expeditions to obtain new species of plants useful in agriculture.

244TH MEETING

The 244th regular meeting was held in the Assembly Hall of the Cosmos Club on November 1, 1932. President J. B. S. NORTON presided; attendance, 97.

E. E. CLAYTON was elected to membership.

F. WEISS remarked on the probability that the current list of botanical publications as published in mimeograph form by the Bureau of Plant Industry Library would have to be discontinued because of lack of funds. He offered the following resolution which was carried: That a sum not exceeding $25.00 be set aside by the Botanical Society for the purchase of mimeograph paper for the Bureau of Plant Industry Library.

N. R. SMITH proposed the following resolution: That an additional paragraph be added to Article IX of the By-laws, to wit:

Article IX

4. At the Annual Business Meeting of the Society those members in good standing who have retired from professional work during the past year shall be elected to honorary membership with all the privileges of membership but without the payment of annual dues.

Discussed by A. S. HITCHCOCK and F. THONE and carried.

Brief notes and reviews: A. S. HITCHCOCK exhibited roots of *Glycine apios*, ground nut, and discussed creeping stems and roots of various other plants. N. E. STEVENS remarked upon the inefficiency of publication. M. B. WAITE

added to the list of roots which have adventitious buds. P. V. MOOK exhibited leaves of exceptional size found in an open cut-over wood. J. B. S. NORTON reported that plowing *Plantago lanceolata* two inches deep either upright or up side down, was effective in killing the plant.

Program: H. B. HUMPHREY: *A Maryland white oak records three hundred years of botanical history.*—The speaker exhibited a polished cross-section from the trunk of an old oak felled near Cabin John. Tags bearing various dates important in botanical science were stuck into the cross-section to illustrate the size of the tree at that time.

R. F. GRIGGS: *The edge of the forest in Alaska and its significance.*—The great coniferous forests which stretch up the coast from Puget Sound and across the continent from Labrador to Alaska terminate in the Katmai district; the Hudsonian forest of white spruce around Naknek Lake on the mainland, and the coastal forest of Sitka spruce at Kodiak. In connection with the work of the Katmai expeditions of the National Geographic Society opportunity was afforded to study the factors fixing the position of the timber line. The trees at the edge of the forest are small and squat suggesting an adverse climate but when examined were found to be growing as rapidly as the same species a thousand miles within its borders to the southeastward, and are likewise reproducing freely. The marginal trees are small because they are young. None of the trees within a mile of the forest border at Kodiak are more than a hundred years old. There are no fallen logs nor other remains of trees older than the present generation. Many trees now standing in thick forest have large dead branches clear to the ground and evidently began life in the open. Three miles back from the forest border the trees are more than three hundred years old and have attained great size. Dead trees and fallen logs are present as in ordinary forests. Several early accounts of Kodiak describe as treeless areas now occupied by heavy forest. Instead of being held in check by climatic factors this forest is rapidly migrating into new territory. Quotations from other observers indicate that similar conditions are general all along the forest front of Alaska and in Scandinavia. The pollens preserved in peat bogs at the forest edge also show that the spruces are recent arrivals—too recent to be represented in the consolidated peat which carries only traces of spruce pollen, such as would be blown in from a long distance. The present trees are thus the only spruces that have grown in the vicinity since the beginning of the bog. The advance of the forest is a secular migration rather than part of a long-term oscillation back and forth. The forest migration thus demonstrated is taken to be a continuance of the readjustment since the last glaciation. It suggests that the vegetation of boreal and north temperate regions generally may not yet have fully recovered from the last glacial period. Means of investigating this question are outlined.

It is of the utmost importance to determine whether vegetation lines are static, held by climatic control as has generally been assumed, or whether they are like the forests of Alaska dynamic, representing merely the present positions of active plant and animal migrations. If it should turn out that we can detect and follow the present movements of species generally an entirely new field of biology will be opened up. (*Author's abstract.*)

PAUL W. BOWMAN: *Pollen analysis of a Kodiak bog.*—Samples of peat were brought from a bog on the island of Kodiak, Alaska, during the summer of 1930 by R. F. GRIGGS. This bog is located several miles from the edge of the spruce forest and is surrounded by well-grown trees. The upper three

feet of this deposit were too soupy to permit the collection of cores. Examination of numerous strata from this point to the bottom at thirteen feet reveals an abundance of spores in most levels. The bulk of these, however, were contributed by several ferns, and only an occasional spore of spruce was seen among thousands of others. In the surface layer of a Quebec bog which is covered with a mixed forest of spruce, fir, and birch three-quarters of the total spores present were contributed by these trees. It may, therefore, be inferred that the Kodiak forest did not exist at this place during the early stages of the formation of this bog and that it advanced to and beyond this location during the formation of the upper three feet of peat. (*Author's abstract*).

Discussed by A. S. HITCHCOCK, C. F. SWINGLE and W. J. HUMPHREYS.

245TH MEETING

The 245th regular meeting was held in the Assembly Hall of the Cosmos Club on December 6, 1932. President J.B.S. NORTON presided; attendance, 80.

The following were elected to membership: R. C. COOK, PAUL R. MILLER, NELLIE W. NANCE, and THELMA BENNETT POST.

N. E. STEVENS made a motion that the dues of the Society be reduced at least by 16⅔ per cent. After some discussion, the motion was amended to reduce the dues to $2.00, making Article IX, Section 1 of the By-laws read, "The annual dues for members of the Society shall be $2.00."

Brief notes and reviews: DAVID GRIFFITHS reviewed the Lily Year-book of the Lily Commission of the Royal Horticultural Society. FREEMAN WEISS remarked upon a fad which may enjoy some vogue in European literature, viz.; the nature of plant immunity and resistance. J. M. SHULL exhibited normal and greatly elongated shoots of *Eleagnus pungens*. CHARLES DRECHSLER exhibited a magnolia leaf infected with the alga *Cephaleuros virescens*. Discussed by F. THONE, M. B. WAITE and W. W. DIEHL.

Program: J. B. S. NORTON: *Lady Roses and Honorable Potatoes.* (*Opinions on naming cultivated plants.*)

The meeting adjourned about 9:15 followed by the annual meeting.

32ND ANNUAL MEETING

The 32nd annual business meeting and election of officers was held following the adjournment of the 245th regular meeting.

The report of the Recording Secretary was read and approved as follows:—

During the past year there have been eight regular meetings, two special meetings and one outing. The annual dinner was held in connection with the 241st regular meeting at the University of Maryland. Average attendance at the regular meetings was 108. Thirteen new members have been elected, three absent members have been reinstated, six have resigned. Two members have died, C. D. MARSH on April 23, and HEINRICH HASSELBRING on November 9, 1932. The membership list shows a net gain of 8 or a total of 210. GEORGE C. HUSMANN, retired during the year, and was elected to honorary membership, in accordance with section 4 of Article IX of the By-laws.

The following officers were elected: *President:* CHARLES BROOKS; *Vice President:* NATHAN R. SMITH; *Recording Secretary:* CHARLOTTE ELLIOTT; *Corresponding Secretary:* FREEMAN WEISS; *Treasurer:* EDITH CASH; *Vice President of the Washington Academy of Sciences:* C. L. SHEAR.

NATHAN R. SMITH, *Recording Secretary*

SCIENTIFIC NOTES AND NEWS

Prepared by Science Service

NOTES

Sixteenth Session of the International Geological Congress.—The third circular for the sixteenth session of the International Geological Congress, which is to meet in Washington, U. S. A., from July 22 to 29, has been issued. It contains full information about meetings and about excursions, with costs. Before the Congress there are excursions to various parts of the eastern United States, lasting from 4 to 12 days, and a trans-continental excursion eastward from San Francisco for those coming to the Congress from the west. For those arriving at New York too late to take part in these longer excursions there will be a number of short trips to nearby areas of geologic interest.

Alternate days during the sessions of the Congress will be given to excursions to areas around Washington.

After the sessions there will be two longer transcontinental excursions, each lasting 31 days, and two shorter excursions, one for the study of the glacial geology of the Central States, and the other for the study of the pre-Cambrian area, including the iron and copper deposits, of the Lake Superior region.

In order to make these excursions generally available, it has been possible, through the generous assistance of the Geological Society of America, to offer the longer excursions at a considerable reduction below actual cost.

For special discussion at the scientific sessions in Washington the following topics are announced:

Measurement of geologic time by any method.
Batholiths and related intrusives.
Zonal relations of metalliferous deposits.
Major divisions of the Paleozoic era.
Geomorphogenic processes in arid regions and their resulting forms and products.
Fossil man and contemporary faunas.
Orogenesis.
Geology of petroleum.
Copper resources of the world.

Membership in the Congress is open to any one interested.

For a copy of the third circular or other information address W. C. MENDENHALL, General Secretary, U. S. Geological Survey, Washington, D. C.

Thirteenth Successive Mild Winter.—Mild winter weather, prevailing in the eastern United States during the season of 1932–33, has continued an unparalleled record for a succession of winters with temperatures above normal, the U. S. Weather Bureau states. Of the past thirteen winters, twelve have given St. Louis above-normal temperatures; New York has had ten out of the thirteen, with the past six all above normal; and Washington can now boast of the thirteenth warm winter in unbroken succession.

Light Water.—Water of low specific gravity has been manufactured in the chemical laboratories of the U. S. Bureau of Standards, by the combina-

tion of hydrogen and oxygen containing high proportions of their respective lightest isotopes (H = 1; O = 16). It is about thirteen parts per million lighter than normal water. Last year "heavy water," containing high proportions of hydrogen isotope 2 and oxygen isotopes 17 and 18, was made in the same laboratory. This "heavy water" has a freezing-point 0.05°C above that of ordinary water, its boiling-point is higher and its refractive index lower. It is expected that the new "light water" will depart from the physical constants of normal water in the opposite way, but to a smaller degree, corresponding to its lesser difference in specific gravity.

New Solar Radiation Station in Sinai.—Messrs. HARLAN H. ZODTNER and FREDERICK A. GREELEY of the Astrophysical Observatory of the Smithsonian Institution sailed on March 4 for Suez, taking with them about six tons of equipment for installing a solar radiation station on Mount Saint Katherine, Sinai, Egypt. The authorities of the Saint Katherine Monastery on Mount Sinai have agreed to construct the observatory and trails. The expedition, financed by JOHN A. ROEBLING, is expected to continue three years, cooperating with the Institution's two solar radiation observatories at Montezuma, Chile, and Table Mountain, California. Mount Saint Katherine, whose summit is about 8,500 feet above sea level, was selected after about twenty months of exploration by Mr. and Mrs. A. F. MOORE.

Marine Shells in Virginia Triassic.—Imprints of fossil seashells have been found in the Triassic Belt of Virginia, near Bull Run, by Dr. ARTHUR BARWICK, acting head of the department of Geology at the Catholic University of America. So far as he has been able to discover, marine shells have not previously been reported from this formation. The Virginia Geological Survey has collected many plants from the Triassic and is cognizant of the footprints of several types of dinosaurs. Little has been found to date, however, that would prevent these deposits from being classified as continental facies as the corresponding deposits of New Jersey and New England are generally thought to be. If these shell remains definitely prove to be members of the Ostreidae, as the cursory studies to date would indicate them to be, it would prove that part of the Triassic deposits of Virginia, at least, were of marine origin.

Activities at the Brookings Institution.—In the Institute of Economics the following research projects have recently been brought to completion:

Advertising Allowances: A Phase of the Price-Making Process LEVERETT S. LYON.

Ten Years of Federal Intermediate Credits, FRIEDA BAIRD and CLAUD L. BENNER.

The American Federation of Labor: History and Outlook, LEWIS L. LORWIN.

Silver: An Analysis of Factors Affecting Its Price, Y. S. LEONG.

Trend Analysis of Statistics: Theory and Technique, MAX SASULY.

When the National Transportation Committee was set up last fall under the chairmanship of the late ex-President Calvin Coolidge, the committee turned to the Brookings Institution to prepare the report on the transportation situation on which they would base their findings. This investigation was organized by Dr. H. G. MOULTON, with a staff consisting of certain members chosen from the Institute for Government Research and from the Institute of Economics, together with several specialists from outside. The investigation has been completed and the committee has issued its analysis

and recommendations. The full report is being published under the title "The American Transportation Problem" in a volume of about 900 pages by the Brookings Institution.

NEWS BRIEFS

One of the last official acts of former President HOOVER was the creation in the Boulder Dam area of a wild life preserve several thousand acres in extent, designed primarily to be a bird refuge.

Work has been started on the reconstruction of the two transit circle houses at the U. S. Naval Observatory.

Dr. BARNUM BROWN, Curator of Fossil Reptiles of the American Museum of Natural History, discussed with U. S. National Park Service officials the possibility of a development at Dinosaur National Monument in Utah that would provide visitors with a view of a dinosaur skeleton left in place on a rocky wall.

The Institute for Government Research of the Brookings Institution, at the request of Governor CLYDE HERRING of Iowa, is engaged upon a financial and administrative survey of that state.

Mr. J. B. MORGAN, 2nd, of radio station W3QP, at Philadelphia, through whom radio communication between the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and its magnetic observatory at Watheroo, Western Australia, is maintained, reports that transpacific radio conditions were nearly perfect during the second week in February.

Work has been begun at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington on an extension to the Experiment Building for the purpose of housing the two-meter Van de Graaff generator which was built and subjected to preliminary tests in Washington during May, 1932. This will make possible experiments with protons and other ions at voltages of one and one-half million volts and more. Atomic-disintegration experiments have heretofore been carried out with a smaller generator in the present building at potentials up to 700,000 volts.

A huge quartz geode, obtained by Mr. E. P. HENDERSON at Keokuk, Iowa, last summer has been placed on exhibition at the U. S. National Museum. It is one of the largest specimens of its kind ever found.

Word has been received from Dr. WALTER HOUGH, Head Curator of Anthropology, that he has found additional remnants of prehistoric canals throughout the Salt River Valley, Ariz.

The expedition which the Carnegie Institution of Washington has organized to explore southern Campeche and northern Guatemala in search of new archaeological sites representing ancient Maya culture left Campeche for the interior on March 4. It will be out about three months and, before returning, will probably go as far south as Uaxactun, Guatemala, where the Institution is conducting important excavation. The expedition is headed by KARL RUPPERT of the Institution's archaeological staff.

Among recent births at the National Zoological Park is a baby eland whose mother died when it was born. After refusing food for a time the little animal consented to take milk from a bottle and is being brought up "by hand."

By exchange with the American Museum of Natural History, New York, the Division of Vertebrate Paleontology, U. S. National Museum has recently acquired two specimens of exceptional interest, the first a nearly complete skeleton of *Moropus* from the Lower Miocene of Nebraska, a clawed ungulate mammal as large as the modern camel. The second is an articulated skeleton of the large carnivorous dinosaur known as *Gorgosaurus libratus* and found in the famous Red Deer River region of Alberta, Canada. Both specimens pertain to genera not previously represented in the paleontological exhibits.

At the National Institute of Health, a vaccine has been made from rat fleas infected with typhus fever, which protects guinea pigs from the disease and promises to develop into a protective vaccine for human beings also.

Maleic acid has been found to be a good preventive of rancidity in edible oils and fats, by Dr. G. R. GREENBANK of the U. S. Department of Agriculture. One part in ten thousand is effective. Dr. GREENBANK has applied for a public patent on his discovery.

PERSONAL ITEMS

Dr. GEORG MASING, Metallurgical Director of Siemens-Halske and President of the Deutsche Gesellschaft für Metallkunde, addressed the scientific staff of the Bureau of Standards on February 17. He also addressed the Washington Society of Engineers and the Washington Chapter of American Society for Steel Treating. Dr. MASING was in this country for the purpose of delivering the Annual Lecture to the Institute of Metals, at the annual meeting of the American Institute of Mining and Metallurgical Engineers in New York, during the week of February 20.

Mr. H. H. BENNETT of the Bureau of Chemistry and Soils, and Mr. LEWIS A. JONES of the Bureau of Agricultural Engineering, U. S. Department of Agriculture, spoke before the National Drainage, Conservation and Flood Control Congress held at Columbus, Ohio, in mid-February.

Mr. WARREN E. EMLEY, Chief of the Organic and Fibrous Materials Division of the U. S. Bureau of Standards, gave a talk before the Central Pennsylvania Section of the American Chemical Society on March 16, at State College, Pennsylvania.

Dr. WALDO SCHMITT, with the Hancock Galapogos Expedition, returned to Panama March 6, after a month's collecting in the Galapogos Islands. The expedition then made collections along the coast of Central America and returned to San Diego the latter part of March.

ANNOUNCEMENTS OF MEETINGS

The ACADEMY will meet at the Cosmos Club on April 20. Dr. HENRY E. SIGERIST, Director of the Institute of the History of Medicine, Johns Hopkins University, will address the Academy.

The Philosophical Society announces the following programs:

April 22. R. W. GORANSON and L. H. ADAMS.—*The precise measurement of birefringence.*

C. S. PIGGOTT.—*Radio-active isotopes and the problem of geological time.*

May 6. A program on "Physical Metallurgical Research."

The National Academy of Sciences will meet April 24, 25, and 26.

The American Physical Society will hold its Washington meeting on April 27, 28, and 29. On the afternoon of April 27, there will be a symposium on hydrodynamics at the Bureau of Standards. One of the speakers will be Dr. TH. VON KÁRMÁN, director of the Guggenheim Aeronautical Laboratory, California Institute of Technology, Calif. The symposium will be followed by an inspection of the National Hydraulic Laboratory.

The Acoustical Society of America will meet in Washington on May 1 and 2.